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VARIATION IN THE MINERAL CONTENT OF KAURI (*Agathis australis* SALISB.) LEAVES WITH RESPECT TO LEAF AGE, LEAF POSITION, AND TREE AGE

By P. J. PETERSON,* Botany Department, University of Auckland, Auckland.

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Summary

Analyses carried out on kauri (*Agathis australis* Salisb.) leaves collected in the autumn have shown that the concentration expressed as a dry weight percentage, of the eight elements studied, namely N, P, K, Ca, Na, S, Mn, and Fe, varied with respect to leaf age, branch aspect, vertical leaf position on the crown, and tree age. The results obtained clearly indicate that, in order to determine the mineral nutrient status of trees, the variations in the percentages of nutrients in leaves from different positions on the tree crown must be minimised by the adoption of a standardised leaf-sampling pattern. It is suggested that for ease of sample collection for kauri nutrient studies, first-year leaves, i.e., those from the current season's growth, be taken from the lower, north-facing branches of solitary trees of a similar age.

INTRODUCTION

The use of foliar mineral analysis is well advanced in many countries in elucidating agricultural and horticultural problems of soil fertility and plant growth, but has seldom been applied to similar problems associated with the growth of forest trees (Puri and Gupta, 1954). In the latter case it is essential, for the successful and consistent application of foliar analysis methods to tree nutrition, that the trends in leaf composition with leaf age and position on the tree be known (Tamm, 1955a).

One of the earliest reports of the variation of foliar analyses in forest trees was that of Mitchell (1936), who showed that the mineral nutrient composition varied with seasonal development. The other early forest tree analysis results have been summarised by Lutz and Chandler (1946) and

*Present address: Plant Chemistry Division, Department of Scientific and Industrial Research, Palmerston North.

Leyton (1948). More recently some deciduous, semi-deciduous, and evergreen forest species from a few countries have been investigated and it has been shown that foliar composition varies with time of sampling in the season, position of leaves on the tree, and, in the case of evergreens, with yearly age of the leaf (Olsen, 1948; Tamm, 1951b, 1955a, b; Puri and Gupta, 1954; White, 1954).

In New Zealand analyses have been reported only for one forest tree, namely *Pinus radiata* D. Don an exotic pine (Askew, 1937; Will, 1957). There is no literature available on the mineral composition of leaves of indigenous forest trees, such as kauri, in this country.

Although analyses have been carried out on several tree species, there is, nevertheless, no standard procedure for leaf sampling (Kramer and Kozlowski, 1960). The present investigation was commenced in order to determine the variations encountered in the mineral composition of kauri leaves of different ages selected from different parts of the tree crown. Information on this point was necessary to determine whether a standardised leaf-sampling pattern was required for a proposed survey of the nutrient status of kauri trees growing on different soil types.

MATERIALS AND METHODS

Leaf Collection

Foliage was collected in the autumn of 1959 (unless otherwise stated) after the vegetative growth for that season had ceased. Autumn collection was adopted, as both the absolute and the percentage content of nutrients in tree species have been reported to be relatively stable at this period (White, 1954; Tamm, 1955a, b).

Branches were removed from each tree with the leaves intact (see *Leaf Preparation*) usually between the hours of 9 a.m. and 3 p.m., according to the procedure of Mitchell and Chandler (1939), although the time of day of sample collection is apparently not of great importance (Ulrich, 1952). Each branch, bearing 300–500 leaves, was enclosed in a large polythene bag and transported as soon as possible after collection to the laboratory.

The variation of mineral content with aspect (and also with age of the leaf) was studied on foliage collected in the autumn of 1958 and also in 1959, from the lowermost north- and south-facing crown branches of two 28 yr old "ricker" trees. These trees were growing on a fertile soil in a private garden at Epsom, Auckland.

Foliage was collected for the study of the variation of mineral content with leaf age, from the lowermost north-facing branches of three solitary trees of uniform size, shape, and age (80–83 yr) growing in a small area of regenerating kauri forest at Albany, Auckland. This forest is regenerating on Whangaripo Clay Hill Soil (New Zealand Soil Bureau, 1954). A single tree (61–63 yr, crown height 35 ft) was chosen from this same area, to study in first year leaves the mineral variation with crown height. For this purpose the tree was felled and four equally spaced branches were

removed from the lower, lower-mid, upper-mid, and upper north-facing positions on the crown.

Material for a study of foliar mineral variation with tree age was also collected in the Albany area. Twenty healthy 1 yr old seedlings which were rooted in soil were collected, as well as north-facing branchlets from three 19–20 yr old saplings. The lowermost north-facing branches were collected from three trees in each of three age groups, namely, 40–42 yr, 61–63 yr, and 80–83 yr. In the oldest tree age group, the typical kauri branching habit was formed, while the two younger groups were "rickers", with branches down the trunk (see Cockayne, 1928). The yearly ages of the seedlings and saplings and also of the leaves, were determined by the number of winter resting bud scars on the stems and branches (Bieleski, 1955, 1959), and in the case of trees by annual ring counts on trunk wood borings (Cheeseman, 1914; Hutchins, 1919).

Trees detached from actual kauri groves were chosen for sample collection in order to avoid the effects of tree density and competition for light and nutrients. These trees were also chosen, as far as possible, isolated from other large trees, to avoid mutual shading which can alter analysis values (Kramer and Kozlowski, 1960). By the adoption of such a procedure, foliage could readily be collected with the aid of a long fork-ended pole from lower branches, without climbing the trees.

Leaf Preparation

Leaves were rapidly removed from the branches in the laboratory, and placed into age groups in cardboard trays prior to drying. All dead or damaged leaves were excluded. Leaves were not washed or cleaned in any way before drying, as elements can readily be leached into the wash water (Tamm, 1951a, 1953; Will, 1955, 1959; Long, Sweet and Tukey 1956; Stenlid, 1958). As soon as possible after sorting, leaves were dried at 100°C for 24 hr. As the time taken to remove batches of leaves was similar, variations in analytical results caused by the exudation of resin should be of a similar order of magnitude for all leaf collections. Analytical values, as a result of resin exudation, may be slightly low. The dried leaves from the individual trees receiving the same treatment were bulked into their respective groups to reduce the number of chemical determinations. The adoption of this procedure, however, limited the statistical treatment of the data. All leaves were stored in glass jars. There were approximately 300 leaves in each age group from bulked samples from three trees, and approximately 100–150 leaves in those samples collected from a single tree. A total of approximately 100 leaves was removed from the 20 seedlings collected.

The dried leaves were powdered by hand in a porcelain mortar, and sub-sampled prior to analysis.

Analytical Methods

All analyses were carried out in duplicate on all the samples and compared with standards run concurrently. Reproducibility of the analytical methods was good in all cases and the difference of duplicates was in-

variably less than 2% for N, K, Ca, and Na; less than 4% for P; less than 5% for Mn, and less than 6% for S and Fe.

The total nitrogen content was determined by the micro-Kjeldahl method after wet ashing with a mixture of sulphuric acid, potassium sulphate, and selenium dioxide (Piper, 1950).

The total content of each of the elements Na, K, Ca, P, S, Fe, Mn, was determined after wet ashing with concentrated nitric acid followed by 70% perchloric acid (Toth, Prince, Wallace and Mikkelsen, 1948) and removal of silica by filtration (Piper, 1950).

The concentrations of Na, K, and Ca, were measured in an "E.E.L." flame photometer. P, Fe, and Mn were measured colorimetrically in a "Spekker" absorptiometer with the appropriate "Chance" glass filter. Phosphorus was determined as the molybdate complex (Fiske and Subbarow, 1925; Chapman, 1932); manganese as permanganic acid after oxidation with periodic acid (Willard and Greathouse, 1917; Toth *et al.*, 1948); and iron as the ferrous orthophenanthroline complex (Toth *et al.*, 1948). The sulphur content was determined gravimetrically as barium sulphate (Scott, 1925; Vogel, 1951).

The results of the foliar analyses are presented in all cases as an average of the duplicates, expressed as a percentage of the oven dry weight.

RESULTS

Effect of Aspect on Leaf Composition

The results of the leaf analyses carried out on the north- and south-facing branches are given in Table 1.

TABLE 1—Variation with Respect to Branch Aspect, of the Percentage of Nitrogen, Phosphorus and Potassium Present in Kauri Leaves of Three Different Ages. Analytical Values are for Two Separate Autumn Leaf Collections from Trees at Epsom.

1958 Collection	Percentage of Oven Dry Weight					
Leaf Age	Nitrogen		Phosphorus		Potassium	
	North Aspect	South Aspect	North Aspect	South Aspect	North Aspect	South Aspect
One year	0·96	0·84	0·113	0·088	0·89	0·91
Two years	0·90	0·79	0·100	0·078	0·63	0·76
Three years	0·87	0·77	0·100	0·078	0·58	0·62
1959 Collection						
One year	0·91	0·87	0·138	0·103	0·90	0·83
Two years	0·85	0·79	0·098	0·089	0·44	0·62
Three years	0·76	0·73	0·080	0·073	0·39	0·52
S.E. per determination	±0·034		±0·011		±0·054	

There is a significantly higher nitrogen and phosphorus content in the leaves from the three age groups from the north-facing than from the south-facing branches. This trend is shown clearly in analyses of material collected both in 1958 and in 1959. The potassium content is significantly higher in leaves from the south-facing than from the north-facing branches in both leaf collections.

Effect of Age of Leaf on Leaf Composition

The percentage content of the elements nitrogen, phosphorus, and potassium decreases with increasing leaf age with samples collected both from north- and south-facing branches from the trees at Epsom (Table 1). Similar trends for these three elements were also observed in foliage from trees in Albany (Table 2).

TABLE 2—Variation in Mineral Content with Respect to Age of Kauri Leaves, Collected from Trees at Albany

Leaf Age	Percentage of Oven Dry Weight							
	N	P	K	Ca	Na	S	Mn	Fe
One year	0·59	0·048	0·55	0·73	0·078	0·037	0·186	0·010
Two years	0·51	0·044	0·50	1·03	0·088	0·043	0·195	0·011
Three years	0·36	0·043	0·48	1·25	0·115	0·056	0·205	0·013
S.E. of estimate	±0·03	±0·013	±0·013	±0·03	±0·007	±0·003	±0·001	±0·001
p*	0.15	0·22	0·17	0·06	0.18	0·15	0·02	0·13

*Level of probability at which linear regression on age of leaf was significant.

Conversely, the elements calcium, sodium, sulphur, manganese, and iron increase with increasing leaf age (Table 2).

Effect of Position of Leaf on Leaf Composition

The figures obtained for analyses of first-year leaves from four different north-facing positions on a tree crown are shown in Table 3.

TABLE 3—Variation of Mineral Nutrient Content of First-year Kauri Leaves with Height of North-facing Sample Position of the Tree Crown

Collection Position	Percentage of Oven Dry Weight							
	N	P	K	Ca	Na	S	Mn	Fe
Upper crown	0·69	0·065	0·41	0·78	0·040	0·044	0·134	0·008
Upper mid-crown	0·71	0·059	0·42	0·84	0·045	0·042	0·146	0·008
Lower mid-crown	0·60	0·048	0·44	0·86	0·058	0·039	0·165	0·009
Lower crown	0·62	0·050	0·49	0·90	0·052	0·056	0·183	0·010
S.E. of estimate	±0·04	±0·004	±0·02	±0·01	±0·008	±0·008	±0·003	±0·0004
p*	N.S.	0·09	0·06	0·02	N.S.	N.S.	0·01	0·06

*Level of probability at which linear regression on collection position was significant.

Phosphorus decreases towards the base of the crown, while potassium, calcium, manganese, and iron increase. Foliar contents of nitrogen, sodium, and sulphur do not show regular trends.

Effect of Tree Age on Leaf Composition

The variation in mineral content of first-year leaves, with age of tree are shown in Table 4.

TABLE 4—Variation of First-year Leaf Nutrient Content with Respect to Kauri Tree Age. Tree Leaves were Collected from North-facing Lower Crown Positions

Tree Age	Percentage of Oven Dry Weight							
	N	P	K	Ca	Na	S	Mn	Fe
Seedlings (1 yr old)	0·71	0·079	0·44	0·95	0·056	0·082	0·098	0·019
Seedlings (19–20 yr)	0·67	0·070	0·49	0·89	0·050	0·096	0·179	0·013
Trees (40–42 yr)	0·62	0·062	0·51	0·93	0·048	0·048	0·178	0·012
Trees (61–63 yr)	0·62	0·050	0·49	0·90	0·052	0·053	0·183	0·010
Trees (80–83 yr)	0·59	0·048	0·55	0·73	0·078	0·037	0·186	0·010
S.E. of estimate	±0·02	±0·003	±0·02	±0·06	±0·011	±0·015	±0·028	±0·002
p*	0·01	0·01	0·06	0·12	N.S.	0·08	0·14	0·04

*Level of probability at which linear regression on age of tree was significant.

Many of the trends with tree age are not large but nevertheless it is possible to recognise definite increases or decreases in mineral concentration with age. With increasing tree age, the concentrations of potassium and manganese increase, while nitrogen, phosphorus, calcium, sulphur, and iron decrease. The sodium content is variable.

DISCUSSION

Although the analyses carried out are limited in number (and significance tests lack precision), they are of interest because they are the only values reported for an indigenous species in New Zealand. They also confirm the general levels of nutrients reported for other tree species.

It is evident that the range of foliar analysis values for some of the nutrients is large and dependent on leaf age, branch aspect, leaf position on the tree crown, and on tree age.

Significant differences in the nitrogen, phosphorus, and potassium composition of south- and north-exposed kauri leaves in both the 1958 and 1959 leaf collections were established. The results obtained can be compared with those for *Picea abies* Karst. where these nutrients have a higher concentration on the south side (northern hemisphere – Tamm, 1955b). This behaviour is probably related to photosynthetic activity of the leaves. Species differences are, however, also involved, since Tamm did not observe a systematic influence of aspect with needles from *Pinus silvestris* L. Like-

wise, White (1954) found no consistent variations in potassium content with respect to needles from *Pinus resinosa* Ait. or *Pinus strobus* L.

Similar trends were obtained for the variation of nitrogen, phosphorus and potassium contents in one, two, and three-year-old foliage from trees growing both at Epsom and at Albany. Current work shows similar trends for these elements and for calcium, sodium, manganese, iron, and sulphur in kauri leaves from nine other forest areas.

Table 5 shows a comparison of the variation with leaf age of the minerals in kauri and *Pinus radiata.*

TABLE 5—Comparison of Changes of Analytical Values with Increasing Age of Kauri and *Pinus radiata* Leaves

Species	Concentration Change											
	Decrease			Increase					N.S. Trend†			
Kauri	K	N	P	Mn	Fe	Na	S	Ca				
Pine (Will, 1957)		N		*	*	Na	*	Ca	P	K	*	
Pine (Askew, 1937)		N	P	Mn		Na	*	Ca		K	Fe	

*Element not determined. †No significant trend.

It may be seen that there is general agreement between the two species in nutrient trends. It is interesting to note that in deciduous tree leaves also, calcium and manganese increase with leaf age, while nitrogen, phosphorus and potassium decrease (Mitchell, 1936; Olsen, 1948; Tamm, 1955b; Puri and Gupta, 1954). The cause of the differences in mineral concentration with increasing age has been attributed in deciduous trees to increases in dry matter content and ash content (Lutz and Chandler, 1946; Ulrich, 1952). In evergreen trees, however, as translocation of some elements from older to younger leaves can occur, it is more difficult to relate mineral content to increases in dry weight (Puri and Gupta, 1954). Further and more detailed studies of mineral variations are required for many other forest trees before it is possible to ascertain the origin of such differences.

When the variations of kauri leaf composition with vertical height are compared with those for *Pinus radiata* (Will, 1957), it is apparent that there is reasonable agreement between species (Table 6).

TABLE 6—Comparison of Changes of Foliar Analyses in Kauri and *Pinus radiata* with Decrease in Height of Sample Position on Tree Crown

Species	Concentration Change									
	Decrease		Increase					N.S. Trend†		
Kauri	P		Ca	K	Mn	Fe		N	Na	S
Pine (Will, 1957)			Ca	K	*	*	P	N	Na	*

*Element not determined. †No significant trend.

In order to clarify the trends shown in this table, similar analyses must be carried out on leaves from many other tree species.

It is to be expected that the mineral content of seedlings would differ from that of trees, as the seedling roots are only in the upper soil zone while the tree roots are present in all soil horizons. In some instances, it is difficult to distinguish between the effect of the age of the seedlings and the effect of growth in only one soil layer, when comparing the results with tree analyses. Nevertheless, the trends observed in tree analyses can be seen in the seedling analyses (Table 4), which is in agreement with the results obtained for *P. radiata* (Askew, 1937). The differences in nutrient content with kauri tree age show a similar spread to those determined for *Betula verrucosa* by Ovington and Madgwick (1959). The individual mineral nutrient trends for kauri are shown in Table 7 together with values for the two species mentioned above.

TABLE 7—Comparison of Change of Foliar Analysis Values in Kauri, *Pinus radiata* and *Betula verrucosa* with Increase in Tree Age

Species	Concentration Change														
	Decrease							Increase						N.S. Trend†	
Kauri	P	N	S	Fe	Ca			K			Mn			Na	
Pine (Askew, 1937)	P		*	Fe	Ca	Na		K			Mn	N			
Betula (Ovington and Madgwick, 1959)	P		*	*				K	Na	*	N	Ca			

*Element not determined. †No significant trend.

The foliar analysis results for trees from Epsom (Table 1) and Albany (Tables 2–4) are markedly different in actual values. This difference is a direct reflection of the different soil types upon which these trees are growing.

In view of the important analysis differences which have been detected in kauri leaves from different parts of a tree, a standardised sampling pattern must be chosen when comparisons of nutrient status between trees are planned. It is suggested that for ease of sample collection, first-year leaves be chosen from the lower north-facing branches. This collection procedure only applies, however, when the trees sampled are solitary and the branches not markedly overshadowed or in competition with others in a high density grove. Should leaf samples be collected from trees growing in groves, first-year leaves from the upper north-facing positions must be chosen to lessen the effects of shade on sample composition. This method would be more time consuming since kauri trees are difficult to climb, unless special equipment is available.

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CLAY MINERALOGY OF NEW ZEALAND SOILS

PART 5: MINERAL COLLOIDS AND GENETIC CLASSIFICATION

By M. Fieldes and N. H. Taylor, Soil Bureau, Department of Scientific and Industrial Research, New Zealand.

(Received for publication, 2 August 1961)

Summary

Mineral colloid assemblages are presented for 15 main classes of zonal and intrazonal soils of Taylor's genetic classification of New Zealand soils. The compositions of the clay fractions of 156 soil samples representing various horizons of these 15 classes are listed in tabular form, summarising results given in previous papers of this series for 22 identifiable constituents in their mineral colloids.

Each soil clay contains between 3 and 8 of the 22 constituents, and the assemblage of mineral colloids in the soils is characteristic of their genetic classes. Relationship between soil properties and the nature of the clays are discussed.

The satisfactory correlation between clay mineralogy and genetic classification confirms the essential soundness of the classification.

Introduction

Many processes occurring in soils, and between soil and plants, may be considered as adustments of chemical equilibria. Elements present in soils tend to become ionised, associated, or bonded, in ways which favour formation of the most stable energy systems. At the present stage of knowledge therefore the chemical viewpoint provides an important means of considering soils. However, while chemistry contributes considerably to the understanding of soils it has so far played a minor role in relation to pedology in soil classification.

The broad problems of the soil chemist and the pedologist are similar. Both are dealing with complicated sets of variable components and considering their behaviour under a variety of circumstances. The pedologist has to contend with variations of the five soil-forming factors, parent material, climate, vegetation (and soil population), topography, and age, in relation to structure, consistence, and general morphology. The chemist is faced with the problem of varying assemblages of many constituents of greatly differing chemical properties present in a medium which is non-uniform and constantly changing. Both have to interpret their judgments in terms of the various needs of agriculturists, foresters, and engineers.

The procedure of integrating properties prior to classifying soils is facilitated for the pedologist by the fact that the morphology of a soil reflects to a considerable extent the chemical and physical properties of its constituents. Morphology therefore is an important criterion of classification. In many countries, in fact, morphology is regarded as the principal basis for classification but even the strongest adherents to morphological classification draw heavily upon miscellaneous information outside of morphology in interpreting their soils.

In New Zealand, classification is based on the coordinated principles of the genetic classification of New Zealand soils (Taylor 1948). This systematic approach overcomes many difficulties inherent in purely morphological classifications by classifying in terms of soil processes as interpreted from morphological observations aided by laboratory evidence. In this way chemical properties are, to a certain extent, incorporated in the fundaments of the classification and part of the effectiveness of the classification is due to this.

The genetic classification provides an effective link between morphology and the five soil forming factors. It may thus be appreciated readily by workers other than those with wide pedological experience. It has the added advantage of simplification. It is difficult to comprehend the implications of five variables as complex as the five soil-forming factors. Three variables can however readily be managed. In effect, for much of the genetic classification the five factors are reduced to three effective variables: (1) parent material; (2) weathering stage, which is an integrated effect of climate, vegetation, topography and age; and (3) degree of leaching which implies effects due to climate, vegetation, and topography.

Chemistry has aided classification by providing measured values of single chemical factors of soils. It has also contributed most effectively through simplified concepts, such as carbon to nitrogen ratio, and percentage base saturation. These concepts give significance to values of more than one property and they are made possible by an understanding of the mechanisms involved.

The science of soils can be advanced by further elucidation of mechanisms. In the genetic classification this implies a more detailed understanding of the nature of processes and weathering stage in any class of soil. In chemistry it demands greater knowledge of the nature of the chemical phases active in the soil.

Pedological assessment of weathering stage of a soil in the genetic classification takes account of the amount and properties of its clay fraction. Chemical properties of a soil are also to a considerable extent concentrated in the clay fraction. Improved knowledge of the nature and properties of clay constituents therefore promises to lead to more effective correlation of pedology and chemistry.

It was for reasons such as these that a broad survey was undertaken of the nature of inorganic colloids in the clay fractions of New Zealand soils.

During the past two decades methods such as X-ray diffraction, infrared absorption, and electron micrography have been developed and improved. These have brought increased precision to the identification of soil clay constituents. Even before these methods were available, however, careful observations by pedologists, aided by results of silicate analyses, had established the nature of the principal clays present in certain New Zealand soils. Thus Taylor (1933) demonstrated the presence of allophane in soils from Mairoa ash, and the kaolinitic nature of many North Auckland soils was appreciated. Nevertheless, detailed knowledge of the nature and distribution of colloids in soil clays was limited and lacked support of direct evidence.

By 1948 when the present survey commenced the genetic classification of New Zealand had been established, and its outline published in map form (Taylor, 1948). This classification was used as a logical basis for the investigation. Soil samples which had been taken in connection with soil surveys were available. With the assistance of the published results of these surveys, and advice of the pedologists concerned, samples of modal soils representative of particular genetic classes were selected.

Various physico-chemical tests were applied to clay fractions of the soils to determine the nature of their inorganic mineral colloids and to give an indication of quantities present.

Many aspects of the work on soil clays at this laboratory have been treated in earlier publications. The relation of colloidal hydrous oxides to high cation-exchange capacities of certain soils was described by Fieldes, Swindale and Richardson (1952). An account of clay-size crystalline silica of abnormal thermal properties was given by Fieldes (1952). Birrell and Fieldes (1952) described the occurrence of allophane in New Zealand volcanic ash soils. Special methods for examining the clays have been developed for cation-exchange capacity (Swindale and Fieldes, 1952) and for silicate analysis (Fieldes, Swindale, Richardson and McDowall, 1954). Fieldes, Swindale and Richardson (1953) presented evidence concerning the form of phosphate in certain soils containing unusual mineral colloids. Information obtained from the present survey of soil clays was used to systematise ideas on chemical weathering of silicates in soil formation (Fieldes and Swindale, 1954), and the latter paper outlined relationships between clay mineralogy and the genetic classification (Taylor, 1948). Unusual forms of halloysite were described by Birrell, Fieldes and Williamson (1955). The evidence of electron micrography concerning the nature of the clays was given by Fieldes and Williamson (1955). An account of the development of kaolin from amorphous oxides through colloids of the allophane series in volcanic ash soils of increasing age was given by Fieldes (1955). The evidence of infrared absorption spectrometry was discussed by Fieldes, Walker and Williams (1956). Fieldes (1957) has presented the evidence of differential thermal analysis, and Fieldes (1958) has given an account of the role of clays in soil fertility.

The terminology used for the mineral colloids and the methods of identification are described in the publications mentioned above. In addition X-ray powder diffraction data were obtained with a Phillips Geiger X-ray spectrometer and were interpreted by methods similar to those described by Brindley (1951).

An early review of the mineralogy of soil colloids by Nagelschmidt (1944) provides a well documented summary of the nature and properties of soil colloids and techniques for their investigation. More recent ideas on structure of clay minerals and X-ray experimental technique are reviewed by Brindley (1951) and other techniques are described by Marshall (1949). Kerr (1951) presents detailed results for standard clay minerals obtained by a variety of physico-chemical methods and the subject of clay mineralogy has been reviewed recently by Grim (1953). Publications of this type and previous papers of the present series provide an adequate account of the nature of individual soil colloids.

TABLE 1—Mineral Colloids in Clay Fractions of Soils

Genetic Class	Genetic Class No.	Lab. No.	Depth in Inches	Horizon	Clay Content Per Cent on Air-dry Soil	Cation Exchange Capacity m.e. per 100 g clay	Soil Type and Parent Rock	Amorphous Hydrous Alumina	Amorphous Hydrous Iron Oxide	Weakly Hydrated Mica	Illite	Clay-vermiculite	Montmorillonite	Interlayered Hydrous Micas	Metahalloysite	Secondary Quartz	Quartz	β – $Fe_2O_3.H_2O$	Lepidocrocite	Goethite	Mineral-organic Complex
Brown-grey earths, weakly leached	1a	2143A	0–3	A	–	–	Arrow steepland soil, from schist	x	x	xx	x	x	–	x	–	–	x	–	–	–	–
		2143B	4–8	B	11	–	,,	x	x	xx	x	x	–	x	–	–	x	–	–	–	–
	1a	5622A	0–4	A	6	15	Conroy fine sandy loam, from schist	x	x	xx	x	x	–	–	–	x	x	x	–	–	–
		5622B	4–8	A–B	9	12	,,	x	x	xx	x	x	–	–	–	x	x	–	–	–	–
		5622C	8–13	B	11	14	,,	x	x	xx	x	x	x	–	–	–	x	–	–	–	–
		5622D	13–15	C	15	15	,,	x	x	xx	x	x	x	x	–	–	x	–	–	–	–
Brown-grey earths, moderately leached	1b	2079A	0–3	A	5	39	Mesopotamia fine sandy loam, from loess	x	x	xx	x	x	–	–	–	–	x	–	–	–	–
		2079B	4–7	A–B	5	38	,,	x	x	xx	x	x	–	–	–	–	x	–	–	–	–
		2079C	8–11	B	5	44	,,	x	x	xx	x	x	–	x	–	–	x	–	–	–	–
	1b	5684A	0–3	A	11	38	Naseby silt loam, from greywacke	x	x	xx	x	x	–	–	–	–	x	x	–	–	–
		5684B	3–6	A–B	13	27	,,	x	x	xx	x	x	–	x	–	x	x	x	–	–	–
		5684C	6–9	B	10	20	,,	x	x	xx	x	x	x	x	–	–	–	x	–	–	–
		5684D	12–16	B–C	9	19	,,	x	x	xx	x	x	x	x	–		–	–	–	–	–
Yellow-grey earth, weakly gammate, weakly leached, weakly gleyed	2b	4896A	0–6	A1	19	44	Raukawa silt loam, from mudstone	–	–	–	xx	–	x	–	–	–	x	–	–	–	–
		4896B	6–9	A2	25	37	,,	–	–	–	xx	–	x	–	–	–	x	–	–	–	–
		4896C	9–12	B1	29	40	,,	–	–	–	xx	–	x	–	–	–	x	–	–	–	–
		4896D	12–18	B2	31	45	,,	–	x	–	xx	x	x	–	–	–	x	–	–	–	–
		4896E	20–26	C1	33	46	,,	–	–	–	xx	–	x	–	–	–	x		–	–	–
Yellow-grey earths, moderately gammate, moderately leached tussock melanized	2c	2819	0–6	A	16	30	Wither silt loam, from loess-like sandstone	–	x	–	xx	–	–	x	–	–	x	–	–	–	–
		2823	32–36	C	10	25	,,	–	x	–	xx	–	–	x	–	–	x	–	–	–	–
	2c	2172A	0–6	A1	10	27	Wither hillsoils; silt loam, from loess-like sandstone	x	x	–	xx	x	x	x	–	–	x	–	–	–	–
		2172B	7–11	A2	12	34	,,	x	x	–	xx	x	x	x	–	–	x	–	–	–	–
		2172C	15–19	B1	25	43	,,	x	x	–	xx	x	x	x	–	–	x	x	–	–	–
		2172D	24–36	B2	15	37	,,	x	x	–	xx	x	x	x	–	–	x	–	–	–	–
		2172E	48–54	C	18	35	,,	x	x	–	xx	x	x	x	–	–	x	–	–	–	–

	2c	5759A	0–4	A	16	32	Timaru silt loam, from loess	x	x	–	xx	x	x	x	–	–	x	–	–	·	–
		5759B	4–10	A	17	30	,,	x	x	–	xx	x	x	x	–	–	x	–	–	–	–
		5759C	10–13	A–B	18	31	,,	x	x	–	xx	x	x	x	–	–	x	–		–	–
Yellow-grey earths, strongly gleyed forest melanized	2h	959A	0–7	A1	17	32	Wharekaka silt loam, from fine sandstone	x	x	–	xx	x	x	x	–	x	x	–	–	–	–
		959B	9–14	A2	19	24	,,	–	x	–	xx	x	x	x	–	x	–	–	–	–	–
		959C	16–22	B1	26	26	,,	–	x	–	xx	x	x	x	–	x		–	–	–	–
		959D	23–28	B2	28	39	,,	–	x	–	xx	x	x	x	–	x	-	–	–	–	–
		959E	30–36	C	21	35	,,	–	x	–	xx	x	x	x	–	x	–	–	–	–	–
	2h	5117A	0–7	A1	15	29	Wharekaka silt loam, from fine sandstone	x	x	–	xx	–	–	x	–	–	x	–	–	·	–
		5117B	8–15	A2	18	26	,,	x	x	–	xx	x	x	x	–	x	x	–	·	–	–
		5117C	15–17	B1	23	28	,,	x	x	–	xx	–	–	x	–	–	x	–		–	–
		5117D	18–26	B2	27	34	,,	–	x	–	xx	x	–	x	–	–	x	–	–	–	–
		5117E	34–38	C	14	27	,,	x	x	–	xx	–	–	x	–	–	x		–	–	–
Yellow-brown earths, moderately gammate, moderately leached	3b	6049A	0–3	A	15	31	Paremata sandy loam from greywacke	–	–	–	xx	–	–	–	xx	–	x	–	–		–
		6049B	3–9	A–B	15	17	,,	–	–	–	xx	–	–	–	xx	–	x	–	·	·	–
		6049C	10–20	B	30	23	,,	–	–	–	xx	–	–	–	xx	–	x	–		–	–
	3b	4846A	0–6	A1	16	29	Pawson silt loam, from loess	x	x	–	xx	–	–	x	–	x	–	–	–	–	–
		4846B	8–10	A2	15	22	,,	x	x	–	xx	–	–	x	–	x	–	–	–	–	–
		4846C	13–18	B1	13	20	,,	x	x	–	xx	–	–	x	–	x	–	–	–	–	–
		4846D	21–27	B2	10	22	,,	x	x	–	xx	–	–	x	–	x	–	–	–	–	–
		4846E	29–33	C	8	22	,,	x	x	–	xx	–	–	x	–	x	–	–	–	–	–
	3b	1678A	0–6	A1	20	45	Kahutara hill soils, from sandstone	–	x	–	xx	x	x	x	–	x	–	–		–	–
		1678B	7–10	A2	16	23	,,	–	–	–	xx	x	x	x	–	x	–	–		–	–
		1678C	12–18	B	13	41	,,	–	x	–	x	x	xx	x	–	x	x	–	–	–	–
Yellow-brown earths, weakly weathered, strongly leached	4	1603A	0–3	A1	12	65	Katrine sandy loam, from greywacke loess	x	x	–	x	x	x	-	–	x	–	x	–	–	–
		1603B	3–6	A2	19	–	,,	x	x	–	x	–	x	–	–	–	–	–		–	–
		1603C	6–12	B	27	78	,,	x	x	–	–	xx	–	–	–	–	–	x		–	–
	4	5621A	0–2	A	16	20	Teviot loam, from schist	x	x	–	xx	xx	x	x	–	–	–	x	–	–	–
		5621B	3–6	A–B	16	21	,,	x	x	–	xx	xx	–	–	–	–	–	x		–	–
		5621C	6–9	B	16	27	,,	x	x	–	xx	xx	x	–	–	–	–	x	–	–	–
		5621D	9–12	B	12	32	,,	x	x	–	xx	xx	–	x	–	–	–	x	–	–	–
		5621E	12–16	B–C	5	36	,,	x	x	–	xx	xx	x	x	–	–	–	x	–	–	–
		5621F	16–19	C	2	38	,,	x	x	–	xx	xx	–	–	–	–	–	x	–	–	–
Yellow-brown earths, moderately weathered weakly leached	5a	631	0–4	A	16	45	Mangaomeko hill soils, from calcareous mudstone	x	x	–	xx	–	xx	x	–	xx	–	–	–	–	–
		632	4–9	B	20	39	,,	–	x	–	x	x	x	x	–	xx	–	–	–	–	–
	5a	5882A	0–5	A	28	32	Kourarau silt loam, from mudstone	–	x	–	xx	x	x	x	–	–	x	?	·	–	–
		5882B	7–14	B	35	35	,,	–	x	–	xx	x	x	x	–	–	x	?		–	–
		5882C	18–24	C	39	38	,,	–	x	–	xx	x	x	x	–	–	x	?		–	–
Yellow-brown earths, moderately weathered, moderately leached	5b	4260A	0–7	A	16	35	Judgeford silt loam, from loess	x	x	–	x	x	x	xx	x	x	x	–	–	–	–
		4260B	10–18	B	15	32	,,	–	–	–	x	x	x	x	x	x	–	–	–	–	–
		4260C	36–40	C	18	30	,,	–	–	–	x	x	x	x	x	x	–	–	–	–	–
	5b	6486A	0–6	A	–	–	Korokoro silt loam, from greywacke	–	x	–	–	xx	–	–	xx	?	x	–	–		–
		6486B	10–16	B	–	41	,,	–	x	–	–	xx	–	–	xx	–	–	–		–	–
		6486C	19–24	C	–	–	,,	–	x	–	–	xx	–	–	xx	–	–	?	?	?	–

TABLE 1—*continued*

Genetic Class	Genetic Class No.	Lab. No.	Depth in Inches	Horizon	Clay Content Per Cent on Air-dry Soil	Cation Exchange Capacity m.e. per 100 g clay	Soil Type and Parent Rock	Amorphous Hydrous Alumina	Amorphous Hydrous Iron Oxide	Weakly Hydrated Mica	Illite	Clay-vermiculite	Montmorillonite	Interlayered Hydrous Micas	Metahalloysite	Secondary Quartz	Quartz	β – $Fe_2O_3.H_2O$	Lepidocrocite	Goethite	Mineral-organic Complex
Yellow-brown earths, moderately weathered, strongly leached	5c	1139A	0–3	A	17	28	Mangawheau sandy clay loam, from greywacke	–	x	–	x	x	x	x	x	x	?	–	?	?	–
		1139B	9–15	B	20	38	,,	–	x	–	x	x	x	x	xx	x	?	–	?	?	–
	5c	6051A	0–3	A1	18	40	Akatarawa silt loam, from greywacke	x	x	–	xx	–	–	x	x	–	x	–	–	–	–
		6051B	3–9	A2	26	37	,,	x	x	–	xx	–	–	x	–	–	x	–	–	–	–
		6051C	10–20	B	11	38	,,	x	x	–	xx	–	–	x	–	–	x	–	–	–	–
	5c	6485A	0–4	A1	–	–	Taita silt loam, from greywacke	–	x	–	xx	–	–	x	x	–	–	–	–	–	–
		6485B	6–12	A2	–	30	,,	–	x	–	xx	–	–	x	x	–	–	–	–	–	–
		6485C	14–16	B	–	–	,,	–	x	–	xx	x	–	x	x	–	–	–	–	–	–
		6485D	18–24	C	–	–	,,	–	x	–	xx	x	–	x	x	–	–	–	–	–	–
Yellow-brown earths, weakly podzolized, (included with 5c)		3656A	0–6	A1	15	48	Renata silt loam, from greywacke	–	?	–	–	xx	–	–	–	–	–	–	–	–	–
		3656B	10–16	B–C	6	50	,,	–	–	–	–	xx	–	–	–	–	–	–	–	–	–
		3656C	18–24	C	15	54	,,	–	–	–	–	xx	–	–	–	–	–	–	–	–	–
Yellow-brown earths, strongly weathered, weakly leached	6a	1475A	0–4	A	41	55	Whirinaki clay loam, from mudstone	x	x	–	x	x	xx	x	–	x	–	–	–	–	–
		1475B	8–13	B	35	44	,,	–	x	–	x	x	xx	x	–	x	–	–	–	–	–
	6a	1499A	0–5	A	22	50	Puhoi clay loam, from mudstone	–	x	–	x	x	xx	x	–	x	–	–	–	–	–
		1499B	7–12	B	20	60	,,	–	x	–	x	x	xx	x	–	x	–	–	–	–	–
	6a	1428A	0–4	A	52	53	Rockvale clay, from calcareous mudstone	–	x	–	x	–	xx	–	–	x	x	–	–	–	–
		1428B	8–13	B	46	53	,,	–	–	–	x	–	xx	–	–	x	–	–	–	–	–
Yellow-brown earths, strongly weathered moderately leached	6b	CI2651	0–4	A	46	25	Marua clay loam, from greywacke	–	–	–	–	–	x	x	xx	x	–	–	?	x	–
		CI2652A	5–11	B	50	23	,,	–	–	–	–	–	x	x	xx	x	–	–	?	?	–
		CI2652B		B–C1	60	21	,,	–	–	–	–	–	x	x	xx	x	–	–	?	?	–
	6b	2404A	0–4	A	33	30	Marua clay loam, from greywacke	–	x	–	–	–	x	x	xx	x	–	–	?	x	–
		2404B	4–8	B	33	29	,,	–	–	–	–	–	x	x	xx	x	–	–	?	?	–

Yellow-brown earths, strongly weathered strongly leached	6c	2098A	0–4½	A	29	40	Hukerenui silt loam, from claystone	x	x	–	–	–	–	x	xx	x	–	–	–	–	–
		2098B	8–14	B	37	35	,,	–	x	–	–	–	–	x	xx	x	–	–	–	–	–
Yellow-brown earth, weakly weathered, moderately podzolized	7a	5683A	0–1	A1	4	43	Polnoon sandy loam, from schist	x	x	–	xx	x	–	x	–	x	–	–	–	–	–
		5683B	2–4	A2	3	23	,,	x	x	–	xx	x	–	x	–	x	–	–	–	–	–
		5683C	5–7	B	8	50	,,	x	x	–	x	xx	–	x	–	x	–	–	–	–	–
		5683D	8–11	B	8	63	,,	x	x	–	–	xx	–	x	–	x	–	–	–	–	–
		5683E	14–15	B–C	6	76	,,	x	x	–	–	xx	x	–	–	x	–	–	–	–	–
		5683F	19–23	C	1	37	,,	x	x	–	–	xx	–	–	–	–	x	–	–	–	–
Podzol	7b	CI2763A		A1	14	15	Wharekohe sandy loam, from sandstone	–	–	–	–	–	–	–	x	xx	x	–	–	–	x
		CI2763B		A2	24	18	,,	–	–	–	–	–	–	–	x	xx	x	–	–	–	–
		CI2764A		B1	56	19	,,	–	–	–	–	–	–	–	xx	xx	x	–	–	–	–
		CI2764B		B2	71	22	,,	–	–	–	–	–	–	–	xx	xx	x	–	–	x	–
Gley podzol	8	5603A	0–8	A	16	22	Maungatua silt loam, from greywacke	–	–	–	xx	x	–	x	x	–	x	–	–	–	–
		5603B	8–8½	A	11	18	,,	–	–	–	xx	x	–	x	x	–	x	–	–	–	–
		5603C	8½–15	B	13	36	,,	–	–	–	xx	x	–	x	x	–	x	–	–	–	–
		5603D	15–17	C	3	–	,,	–	–	–	xx	x	–	x	x	–	x	–	–	–	–
Rendzina	11	1438A	0–3	A	55	73	Arapohue clay, from argillaceous limestone	x	–	–	–	x	xx	–	–	x	–	–	–	–	–
		1438B	3–6	B	56	75	,,	x	–	–	–	–	xx	–	–	x	–	–	–	–	–
		1442A	0–3½	A	36	56	,,	x	–	–	–	–	xx	–	–	x	–	–	–	–	–
		1422B	3½–8	B	36	48	,,	x	–	–	–	–	xx	–	–	x	–	–	–	–	–
	11	5935A	0–5	A	35	38	Kourarau clay loam, from limestone	–	x	–	xx	x	x	x	–	–	x	–	–	?	–
		5935B	6–10	B	50	31	,,	–	x	–	xx	x	x	x	–	–	x	–	–	?	–
		5935C	12–18	B–C	78	30	,,	–	x	–	xx	x	x	x	–	–	x	–	–	?	–
Gley soil	17	6053B	3–9	A–G	30	30	Gollans silt loam, from alluvium	–	–	–	xx	x	–	x	–	–	x	–	–	–	–
		6053C	9–18	G	30	25	,,	–	–	–	xx	x	–	x	–	x	x	–	–	–	–
		6053D	18–24	G–C	30	20	,,	–	–	–	xx	x	–	x	–	x	x	–	–	–	–

Symbols: xx dominant, x present, ? doubtful, – not detected.
Note: Calcite was present in the clays of samples 4896, 2172, and 1438.

This paper records the distribution of clay constituents of New Zealand soils typical of various genetic classes, and discusses the results in terms of the genetic classification (Taylor, 1948). Work on the subject is continuing and may yield further information, particularly concerning the nature of amorphous colloids. However, the general results given here have been established and under consideration for several years so that it is unlikely that subsequent work will cause major changes in the results.

METHODS

Soils were in all cases treated with hydrogen peroxide to remove organic matter. Clay fractions less than 2 μ in equivalent spherical diameter were obtained by repeatedly dispersing the soil in sodium hydroxide at pH 10 and centrifuging to separate the clay. Clay fractions were flocculated with sodium chloride, washed free of chloride with 80% ethyl alcohol, washed three times with acetone, and air dried. Clay fractions from deferrated soils were also studied. Free iron oxides were removed from the soils prior to clay separation, in order to promote dispersion of the remaining colloids during fractionation and to aid orientation for X-ray studies.

RESULTS

Results are summarised in Tables 1 and 2, which list genetic class, class number, laboratory number, depth, horizon, percentage clay, cation-exchange capacity of clay, and nature of mineral colloid constituents.

Figures for percentage clay in Tables 1 and 2 are based on the yields of clay obtained by the sedimentation method described above. In Table 1 clay percentages listed are those obtained by fractionation of soils pretreated with hydrogen peroxide and deferrated by Jeffries (1946) method. Amounts of free iron oxides removed from the soils of Table 1 are usually less than 2% of the air dry soil. Figures for clay yield could not be repeated exactly but agreement of replicates was within $\pm$ 5% of the percentage clay. Agreement of the same order was obtained between values of percentage clay obtained from a number of yellow-grey and yellow-brown earths by the repeated sedimentation method, and by a standard hydrometer method. Clay contents listed in Table 1 thus have roughly quantitative significance.

In Table 2, percentages of clay listed were obtained by repeated sedimentation of soils without removal of free iron oxide. Values for these soils after deferration are uncertain as they may contain unstable clay constituents such as allophane which decomposes during treatment (Birrell and Fieldes, 1952). Values without deferration are also indefinite owing to the presence of undispersed aggregates of clay. Many soils continue to yield clay after very many sedimentations and in the case of yellow-brown loams in particular it is frequently necessary to discontinue the separation procedure while appreciable amounts of clay remain unseparated. Clay yielded in the later stages may be derived from aggregates of clay or from mechanical breakdown of structures of material in coarser fractions. The figures for clay content in Table 2 are therefore of doubtful significance. They are, however, considered to be roughly quantitative except in the case of yellow-brown loams.

Values of cation-exchange capacity listed in Tables 1 and 2 were estimated by the semi-micro method of Swindale and Fieldes (1952). These figures are reproducible to ± 5%. Cation-exchange capacities in Table 1 are for deferrated clays and those in Table 2 are for ferrated clays.

Ferrated and deferrated clays of all of the soils listed have been examined by methods of X-ray diffraction, differential thermal analysis, electron micrography and determination of cation-exchange capacity. Results have been checked for certain constituents by infrared absorption spectrometry of selected samples (Fieldes *et al.* 1956), by silicate analysis, and by ethylene glycol absorption measurements. The nature of the mineral colloids in each clay as expressed in Tables 1 and 2 has been judged from the combined evidence of these techniques.

In the tables an indication is given of mineral colloid constituents present and of the dominant constituent, if any, in each clay. It is possible by making certain assumptions to give more definite expression to judgments of quantities, and Swindale (1955), for instance, has outlined methods which permit percentage values to be assigned to a number of constituents. Figures obtained in this way are of use in detailed studies. In the present broad survey of soils, some of which contain constituents whose properties are not fully known, estimation of percentages was not attempted pending further investigations of quantitative methods. The method of ethylene glycol absorption for estimation of montmorillonite, for example, has proved not specific for this clay mineral in many New Zealand soils, and figures derived from such data could be misleading.

It will be seen from Tables 1 and 2 that 22 constituents have been recognised in New Zealand soil clays, and that the assemblages of mineral colloids vary in a characteristic way from class to class.

Results and Discussion

Soils of the classification are divided into three broad categories, zonal, intrazonal, and azonal. *Azonal* soils are not included in the present work. They represent soils such as skeletal soils formed on steep slopes and Recent soils from alluvium. These soils are relatively young and profile development is limited.

Zonal and intrazonal soils have not been seriously influenced by recent accumulation and have been formed on gently rolling to rolling slopes so that erosion in general has been slow. The age of these soils is such that they have good profile development, and they may be considered to have approached dynamic equilibrium in relation to their soil processes.

Zonal soils are derived from "normal" or average parent materials which are neither highly siliceous nor highly basic and which approximate in composition to the average composition of the lithosphere. Parent materials of the zonal soils are therefore similar, and distinctions between classes of zonal soils are due mainly to climate and vegetation.

Intrazonal soils are comparable in profile development with zonal soils, but their properties are modified by extreme factors such as parent materials

that are highly acidic or basic. Because of their relatively low content of mineral colloid no consideration is given here to zonal and intrazonal peats or to yellow-brown sands.

Zonal Soils

Zonal soils are derived from greywacke, shales, and other rocks which are similar in chemical composition to acid-intermediate rocks. They contain varying amounts of mixed micas, feldspars, and quartz, with small amounts of more basic minerals. The nature of the clay varies markedly with the genetic class of the soil which in turn is related to degree of weathering (Hurst, 1951). Micas are the most readily weathered primary minerals in the parent materials of zonal soils and clay fractions of these soils consist predominantly of hydrous micas. A number of stages can be distinguished in the degradation of mica. With increasing weathering mica produces weakly hydrated mica, illite, interlayered hydrous micas, clay-vermiculite, and montmorillonite. Strong weathering degrades micaceous clays to kaolin and finally to secondary silica. These and related effects are illustrated in Table 1, and they are discussed below in relation to the various genetic classes.

BROWN-GREY EARTHS (Genetic Class 1)

Brown-grey earths are formed under a semi-arid climate and at relatively low temperatures. An average mean temperature of 47°F, and mean annual rainfall in the range 12 to 25 in., are recorded for soils of this class.* Under these conditions chemical weathering is slow, soil profiles are shallow (8 to 16 in.) and their clay contents, 5% to 15%, are the lowest observed for the zonal soils examined. Parent materials include schist, greywacke, and loess. Weathering of mica is the dominant process of clay formation but weathering stage is not advanced. Clay consists of weakly hydrated mica, illite, clay-vermiculite, and amorphous hydrous oxides of aluminium and iron.

Electron micrographs show that the clay fractions (less than 2 μ) of these soils consist mostly of large plates between 1 and 2 μ across. Many of the plates are thick like those of illite and weakly hydrated mica, but some are very thin like those of vermiculite. Basal spacings near 10 Å in X-ray diffraction (XRD) patterns confirm the presence of illitic clays, and a 14 Å series of X-ray diffraction lines in all clays of soils of genetic class 1 suggest the presence of clay vermiculite. Differential thermal analysis (DTA) patterns confirm clay-vermiculite, and show that micaceous clays are weakly hydrated, and that kaolin is not present. Montmorillonite if present in these soils is in low concentration. Thus although it was identified by XRD in the 0 to 0·2 μ fraction of sample 2079C its amount was estimated as less than 0·05% of the soil. The predominance of large plates and the absence of fine particles of montmorillonite give clays of brown-grey earths a characteristic appearance in electromicrography.

*Climatological data in this paper are taken from a departmental chart (pers. comm. by N. H. Taylor and I. J. Pohlen).

TABLE 2—Mineral Colloids in Clay Fractions of Soils

Genetic Class	Genetic Class No.	Lab. No.	Depth in Inches	Horizon	Clay Content % on Air-dry Soil	Cation-exchange Capacity m.e. per 100 g Clay	Soil Type and Parent Material	Amorphous Hydrous alumina	Amorphous Hydrous Iron Oxide	Amorphous Hydrous Silica	Allophane B	Allophane AB	Allophane A	Metahalloysite	Montmorillonite	Secondary Quartz	Quartz	β–$Fe_2O_3.H_2O$	Lepidocrocite	Goethite	Gibbsite	Boehmite	Anatase	Phosphated oxides	Mineral-organic Complex
Yellow-brown pumice soils, weakly and moderately leached	13a	6310A	0–5	A	4	35	Kaharoa sand, from rhyolitic ash	–	–	xx	xx	–	–	–	–	–	–	–	–	–	–	–	–	x	x
		6310B	5–6	B	4	–	,,	–	–	?	xx	–	–	–	–	–	–	–	–	–	–	–	–	–	x
		6310C	7–14	C	5	32	,,	–	–	?	xx	–	–	–	–	–	–	–	–	–	–	–	–	–	x
	13a	5849A	0–4	A	3	60	Taupo sandy silt, from rhyolitic ash	–	–	x	xx	–	–	–	–	–	–	–	–	–	–	–	–	x	x
		5849C	7–9	B	7	90	,,	–	–	?	–	xx	–	–	–	–	–	–	–	–	–	–	–	–	x
	13a	1226A	0–7	A	9	80	Mahia fine sandy loam, from rhyolitic ash	–	–	x	–	xx	–	–	–	–	–	–	–	–	–	–	–	–	x
		1226C	11–18	B	7	148	,,	–	–	?	–	xx	–	–	–	–	–	–	–	–	–	–	–	–	x
Yellow-brown loams, weakly and moderately leached	14a	6165	0–6	A	15+	107	Tirau sandy loam, from Tirau ash (dominantly rhyolitic)	–	x	–	–	–	xx	x	–	–	–	–	–	–	–	–	–	–	x
	14a	6166	0–6	A	15+	115	,,	x	x	–	–	–	xx	x	–	–	–	–	–	–	–	–	–	–	x
	14a	6204	30	C	25+	99	,,	–	–	–	–	–	xx	x	–	–	–	–	–	–	–	–	–	–	–
	14a	6167	0–6	A	15+	80	Ohaupo silt loam, from andesitic ash	–	–	–	–	–	xx	x	–	–	–	–	–	–	–	–	–	–	x
	14a	614	6–12	A	20+	66	Egmont brown loam, from andesitic ash	–	–	–	–	–	xx	–	–	–	–	–	x	–	–	–	–	–	x
	14a	SB6674	30	C	13+	–		–	–	–	–	–	xx	–	–	–	–	–	x	–	–	–	–	–	–
Yellow-brown loam, strongly leached	14d	PC 173	0–6	A	–	–	Mairoa silt loam from andesitic ash	–	–	–	–	–	xx	x	–	–	–	–	–	–	x	–	–	–	–
Brown granular clays, moderately leached	15a	CI1845	0–4	A	20	30	Hamilton clay loam, from andesitic ash	–	x	–	–	–	x	xx	x	–	–	–	–	–	–	–	–	–	–
		CI1846B	9–15	B	25	21	,,	–	x	–	–	–	–	xx	x	–	–	–	–	–	–	–	–	–	–
		CI1846F	32–36	B	70	21	,,	–	x	–	–	–	–	xx	–	–	–	–	?	?	–	–	–	–	–
	15a	CI1849A	0–3	A	25	27	,,	–	–	–	–	–	x	xx	x	–	–	–	–	–	–	–	–	–	–
		CI1849B	3–6	B	30	44	,,	–	–	–	–	–	x	xx	x	–	x	–	–	–	–	–	–	–	–
Brown granular clays, strongly leached	15b	3200A	0–4	A	43	17	Rangiuru clay, from andesite	–	x	–	–	–	–	xx	–	–	–	–	x	x	–	–	–	–	–
		3200B	6–12	B	46	19	,,	–	x	–	–	–	–	xx	–	–	–	–	x	x	–	–	–	–	–
	15b	3307A	0–4	A	15	25	,,	–	x	–	–	–	–	xx	–	–	–	–	x	x	–	–	–	–	–
		3307B	6–11	B	18	24	,,	–	x	–	–	–	–	xx	–	–	–	–	x	x	–	–	–	–	–
Brown granular clays, strongly podzolized (included with 15b)	–	1440A	0–5½	A1	9	13	Tinopai sandy loam, from andesitic tuff	–	–	–	–	–	–	–	–	x	xx	–	–	–	–	–	–	–	–
		1440B	10–15	A2	10	13	,,	–	–	–	–	–	–	x	–	xx	x	–	–	–	x	?	–	–	?
		1440C	16–19	B1	11	22	,,	–	–	–	–	–	–	xx	–	xx	xx	–	–	–	x	?	–	–	–
		1440D	21–25	B2	25	22	,,	–	–	–	–	–	–	xx	–	–	x	–	x	x	x	–	–	–	–
Red and brown loams, weakly and moderately leached	16a	1680A	0–5	A	12	51	Middlehurst silt loam, from basalt	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		1680B	6–11	B–C	14	41	,,	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		1400A	0–3	A	28	36	Whatatiri clay loam, from basalt	x	x	–	–	–	–	x	–	–	–	x	–	–	xx	–	–	x	–
		1400B	7–13	B	27	36	,,	x	x	–	–	–	–	x	–	–	–	x	–	–	xx	–	–	x	–
	16a	SB6676	30	C	78	–	,,	–	–	–	–	–	–	xx	–	–	–	–	–	–	xx	–	–	–	–
	16a	1390A	0–2	A	–	–	Kiripaka silt loam, from basalt	–	x	–	–	–	–	x	–	–	–	–	–	–	xx	–	–	x	x
		1390B	7–13	B	–	–	,,	–	–	–	–	–	–	xx	–	–	–	–	–	x	xx	x	–	x	x
Red and brown loams, strongly leached	16b	1466A	0–6	A	31	–	Kerikeri friable clay, from basalt	–	–	–	–	–	–	x	–	–	–	–	–	–	xx	–	–	–	x
		1466B	6–12	B	27	–	,,	–	–	–	–	–	–	x	–	–	–	–	–	–	xx	–	–	–	x
Red and brown loams, strongly leached, with ironstone nodules	16c	4739A	0–6	A	–	–	Okaihau gravelly friable clay, from basalt	–	–	–	–	–	–	x	–	–	–	–	x	x	xx	?	x	x	–
		4739B	8–16	B	–	10	,,	–	–	–	–	–	–	x	–	–	–	–	x	x	xx	?	x	x	–

Symbols: xx dominant, x present, ? doubtful, – not detected.

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Deferrated clay of the weakly leached brown-grey earths, genetic class 1a, has exchange capacity of the order of 10 to 15 me. per 100 g. This is markedly less than that of the clay of any other zonal soil and it is indicative of the weak stage of hydration of the micas and the low contents of expanding mica even in interlayers. Conroy soils of genetic class 1a, have sandy texture due to low clay content. Horizontal layering effects and platy nature of soil aggregates in A and A-B horizons are, however, likely to be associated with horizontal orientation of the unusually large platelike clay particles.

Deferrated clay of moderately leached brown-grey earths, genetic class 1b, shows a marked increase in cation exchange capacity, range 20 to 40 me. %, which is comparable with that of clays of yellow-grey earths developed under higher rainfall and stronger weathering conditions. Clays of soils of genetic class 1b however, have little montmorillonite and the increase in exchange capacity over class 1a appears due to a greater proportion of clay-vermiculite. The granular and blocky soil structure of moderately leached brown-grey earths, in contrast to the platy structures of the weakly leached class, may be due to greater swelling properties of its clays and in some cases to higher clay content.

In genetic classes 1a and 1b, brown-grey earths, the pH is medium to high (5·6 to more than 7), base saturation per cent is in the range 40 to 100 and calcium is the dominant exchangeable cation. Similar conditions in more weathered soils would favour formation of montmorillonite (Fieldes and Swindale, 1954). The fact that weathering of micas has not proceeded past the clay vermiculite stage is due to low intensity of weathering owing to low temperatures and the long periods during which the soil moisture content is low.

YELLOW-GREY EARTHS (Genetic Class 2)

Yellow-grey earths are formed from zonal parent material under more intense weathering conditions than brown-grey earths. Average mean temperature of these soils is 52°F and mean annual rainfall 20 to 40 in. Micaceous clays of this class are correspondingly more hydrated.

The results of XRD and DTA show that illite is the dominant mineral in the clay fraction and that most soils of this class contain appreciable amounts of montmorillonite. There is a marked difference between the appearance of electron micrographs of clays from brown-grey earths and yellow-grey earths due to the presence of fine particle-size plates of montmorillonite in the latter but not the former. Most clays of this soil class also contain clay-vermiculite and interlayered hydrous micas. An exception, however, is the Raukawa silt loam, class 2b, the clay of which contained mainly illite and montmorillonite. In this case infrared absorption indicated a small amount of calcite in the clay. High calcium, as will be seen later for rendzinas, accelerates formation of montmorillonite in micaceous clays.

Cation-exchange capacities of the deferrated clays range between 25 me. and 45 me. per 100 g. A frequent feature of the cation exchange values is a

significant drop from A_1 to A_2 horizons followed by a significant increase for lower horizons. This may be associated with elevation of fine particle size clay from the A_2 horizons.

Evidence of X-ray diffraction shows that in many yellow-grey earths clay fractions of topsoils exhibit mainly the 10 Å spacings of illite but there is an increase in the amount of 14 Å constituent (of the glycerol clay) with increasing depth. This is accompanied by rising cation-exchange capacity and has been interpreted as an increase in the amount of clay-vermiculite in the clay fraction in lower horizons. Chemistry of the profiles shows an unusual change in the ratio of exchangeable calcium to exchangeable magnesium. This ratio may be typically 2 : 1 in a yellow-grey earth topsoil and 1 : 2 in its subsoil (Gibbs, 1945). Arbuckle (pers. comm.) in a thesis on this phenomenon showed that considerable cation exchange capacity resided in the silt fractions of a Wharekaka soil and P. G. Harris (pers. comm.) showed petrologically that coarse fractions of this soil contained considerable vermiculite.

Thus clays in subsoils of yellow-grey earths contain considerable clay-vermiculite. The apparent absence of clay-vermiculite in some corresponding topsoils has been discussed by Fieldes and Swindale (1954) who find evidence that 14 Å clay-vermiculite formed in subsoils may fix potassium and revert to a form of 10 Å-illite when it encounters relatively high potassium from the organic cycle in the topsoil. Further evidence for this is the fact that although topsoil clays have the 10 Å spacing of illite they are shown by electronmicrographs to contain thin plates which could be clay-vermiculite (Fieldes and Williamson, 1955), and in DTA show heat effects similar to the latter mineral (Fieldes, 1957). On this evidence part of the clay of topsoils of yellow-grey earths is possibly more like 10 Å-vermiculite than illite and it has been suggested that this form may be capable of fixing further potassium and thus resemble the vermiculitic clay of high potassium fixing power found in Dutch soils by Temme and van der Marel (1953). In Table 1 clay-vermiculite shown in the topsoils of zonal soils is of the 10 Å type and in this respect the table expresses the evidence of DTA rather than XRD. Further elucidation of the role of vermiculite in yellow-grey earths is desirable.

In the presence of organic matter of the A horizon, yellow-grey earths exhibit a weak crumb structure. Their subsoils are massive and frequently have an indurated pan 12 in. or more in thickness. The massive structure of the subsoil and the gammation (γ-shaped cracking) characteristic of yellow-grey earths are due to effects of expansion and contraction during wetting and drying of expanding micaceous clays present in the subsoils.

YELLOW-BROWN EARTHS

The trends of micaceous weathering shown in brown-grey earths and yellow-grey earths are continued and extended in soils classed as yellow-brown earths, which experience a wider range of weathering and leaching, and a correspondingly wider range of climatic conditions. Thus weakly weathered yellow-brown earths, genetic class 4, have average mean temperature as low as 42°F and mean annual rainfall of 35 to 70 in. Moderately weathered yellow-brown earths, genetic class 5, have average mean tempera-

ture 52°F and mean annual rainfall of classes with different leaching, ranging from 40 to 100 in. Strongly weathered yellow-brown earths, genetic class 6, have average mean temperature 57°F and mean annual rainfall from 50 to 100 in. Included in this part of the discussion are soils transitional between yellow-grey and yellow-brown earths, genetic class 3, whose climatic conditions are also intermediate.

Owing to the wide range of conditions experienced over the yellow-brown earth group, all stages of micaceous weathering appear in clay fractions of different genetic classes within this group. In order to elucidate the relation of micaceous clay minerals to soil properties and weathering stage in the subsequent discussion, a brief summary of their properties is given below.

Clay minerals representing six definite stages of degradation of micas (mica, illite, clay-vermiculite, montmorillonite, metahalloysite, and silica) found in yellow-brown earths and to a restricted extent in the other zonal soils are listed in Table 3, which also assigns weathering stage numbers, and lists potassium content, silica:alumina molecular ratios, cation-exchange capacities, X-ray basal spacings, and particle-size range. Values listed are typical of those given by Nagelschmidt (1944) and Brindley (1951) and supported in this work. The figures provide clues to some of the properties of these mineral colloids. The course of micaceous weathering in zonal soils is indicated in Table 4.

Primary Micas (stage 0)

Primary micas have high potassium contents; low-cation-exchange capacity; low basal spacing; and large particle-size. They are non-swelling and lack colloidal properties. Owing to relatively rapid weathering in yellow-brown earths primary micas do not occur extensively in the clay fractions, though they may still exist in coarser particles.

Illite (stage 1)

Illite has lower potassium, indicating that in its formation potassium has been released. Potassium is released between weathering stages 0–1, 1–2, and 2–3 of the micaceous weathering sequence in Table 3. The presence of two or more of stages 0 to 3 in the clay of any soil may usually be taken as an indication that degradation of micaceous materials containing potassium is proceeding actively and that reasonable amounts of potassium should be coming available for plants.

Clay-vermiculite (stage 2A)

Clay-vermiculite has special properties in relation to potassium and ammonium (Barshad, 1946). In soils subject to erosion clay-vermiculite formed in subsoils ultimately reaches topsoils where the concentration of potassium and ammonium in soil solution is liable to be higher. These ions may now be absorbed in a form which is not readily exchangeable and potassium fixation has been reported (Temme and van der Marel, 1953) in Dutch soils containing clay similar to clay-vermiculite. Like illite and montmorillonite, however, this clay mineral has considerable cation-exchange capacity, implying power to retain and exchange other cations such as calcium.

TABLE 3—Weathering Stages of Micas in Zonal Soils

Weathering Sequence Stages	Mineralogy	Potassium Atoms per Unit Cell (approx.)	$SiO_2 : Al_2O_3$ Molecular Ratio of Mineral	True Cation Exchange Capacity (me. %)	X-ray Basal Spacings (glycerol)	Particle-size (μ)
0	Primary micas	1·5	3 ± 1	very low	9·9	1
1	Illite	1·0	3 ± 1	30	10·2	1
2A	Vermiculite*	0·5	3 ± 1	100	14·0	1
2B	Montmorillonite	0	3 ± 1	100	17·8	0·1 to 0·5
3	Metahalloysite (+ SiO_2)	0	$1\frac{1}{2} \pm \frac{1}{2}$	very low	7·4	0·2 to 1·0
4	Secondary silica	0		–	amorphous	much very small, but grows with age.

*Clay-vermiculites in N.Z. zonal soils appear to be mainly dioctahedral.

TABLE 4—Course of Micaceous Weathering in Zonal Soils

Mica (Stage 0) → Illite (Stage 1)

Illite (Stage 1) → H → C-Vermiculite (Stage 2A)

Illite (Stage 1) → H and Ca → C-Vermiculite + Montmorillonite (Stage 2)

Illite (Stage 1) → Ca → Montmorillonite (Stage 2B)

C-Vermiculite + Montmorillonite (Stage 2) → H → Metahalloysite (Stage 3) → H → Silica (Stage 4)

(1) H indicates strong leaching at low pH; Ca indicates restricted leaching at relatively high base saturation; H and Ca indicates intermediate leaching conditions.

(2) C-Vermiculite indicates clay-vermiculite, often dioctahedral in New Zealand soils.

Montmorillonite (stage 2B)

Montmorillonite has no potassium reserve. Its X-ray basal spacing indicates that, like vermiculite, but unlike illite and mica, it is capable of expanding its structure very considerably under appropriate conditions. The solid portion of such clays, for instance, will vary in volume by 50% or more between dry and wet conditions. Expansion and contraction of this nature leads to a compact soil and restricts drainage which in turn limits leaching and permits increase in concentration of calcium and magnesium ions on the exchange complex. The latter ions because of their charge and size, are particularly active in wedging apart layers of any hydrous micas present and permitting the complete removal of interlayer potassium to form more montmorillonite (Jackson *et al.*, 1951). At the same time the pH of poorly drained soils remains high, a condition under which decomposition of montmorillonite to halloysite and silica is limited (Fieldes and Swindale, 1954). Thus under conditions where sufficient montmorillonite has been formed to impede drainage, conditions of weak leaching and wet and dry cycles favour formation of further montmorillonite at the expense of other micaceous minerals. Montmorillonite has fine particle size and strong colloidal properties.

Clay-vermiculite on the other hand tends to be the stable form of micaceous clay under strong leaching at low pH (Fieldes and Swindale, 1954). Under these conditions there is insufficient calcium ion present to favour its breakdown to montmorillonite. Furthermore, hydrous oxides of aluminium and iron which accumulate under strong leaching at low pH give the subsoils good structure and permit continued good drainage.

Thus just as montmorillonite tends to accumulate under poor drainage, clay-vermiculite accumulates under good drainage particularly at temperatures low enough to limit further breakdown of clay-vermiculite to metahalloysite.

Montmorillonite has high cation-exchange capacity and soils containing much of it need to be limed to higher percentage base saturations than other yellow-brown earths.

Metahalloysite (stage 3)

Metahalloysite has no potash reserves. This may not mean that soils high in metahalloysite are necessarily deficient in potassium since weathering conditions capable of producing metahalloysite appear also capable of weathering potash feldspars if these are present.

Secondary Silica (stage 4)

Secondary silica and quartz accumulate in topsoils under strong podzolising conditions which remove alumina from micaceous clays and metahalloysite. Owing to its fine particle size and leaf-like shape (Fieldes and Williamson, 1955) it is capable of consolidating to form massive soil structures. Topsoils of podzols high in colloidal secondary silica are low in total plant nutrients. On the other hand cations and anions are not adsorbed

strongly on this colloid and compared with other soil constituents it offers little competition with the organic cycle for plant nutrients. Thus it is non-fixing and small amounts of applied fertiliser may be readily taken up by the plants.

Distribution of Clay-minerals

The distribution of dominant clay-minerals in various genetic classes of yellow-brown earths is shown in Table 5. which summarises results for these soils listed in Table 1 and general results for other soils of this type examined. Intrazonal factors are present even in zonal soils and when strong they are reflected in clay-mineralogy. In Table 1 it will be seen that the Paremata and Korokoro soils which were considered as genetic classes 3b and 5b respectively on the basis of morphology, parent material, and climate, actually contain more metahalloysite than is expected for their weathering stage. There is evidence that the greywacke of their parent materials had probably been weathered in a previous climatic cycle, so that consideration needs to be given to the effect of this factor on classification. Similar considerations may apply also to high clay-vermiculite in the Korokoro soil. For most of the modal soils nominated, however, deviations from the pattern have been slight.

The following properties of yellow-brown earths are illustrated by the data of Tables 1 and 5:

(1) Montmorillonite tends to be high in weakly leached, poorly drained soils (genetic classes 5a and 6a) and low in corresponding strongly leached soils (5c and 6c).

(2) Vermiculite formation is favoured by increased leaching and podzolising of the less weathered soils.

(3) Metahalloysite is common in strongly weathered strongly leached soils.

(4) Weathering stage of micaceous clay minerals increases with increased weathering of the soils.

(5) Minerals present in early weathering stages have nutrient reserves but low rate of release.

(6) At intermediate weathering stages, several types of clay mineral coexist and structural breakdown must be actively proceeding. These are conditions in which plant nutrients are rapidly released.

(7) The nature of the clay indicates that at advanced weathering stages nutrient reserves are limited.

(8) Characteristic assemblages of the minerals are present in the various genetic classes.

(9) Trends noted above in the clay mineralogy of brown-grey earths and yellow-grey earths are continued in the yellow-brown earths.

TABLE 5—Distribution of Dominant Clay Minerals Derived from Mica in Yellow-brown Earths

Weathering Stage	Genetic Class	Weakly Leached	Moderately Leached	Strongly Leached	Podzolised
Weakly weathered	4			*4* Illite (1) C-Vermiculite (2A)	
Moderately weathered	5	*5a* Illite (1) Montmorillonite (2B)	*5b* Illite (1) C-Vermiculite (2A) Montmorillonite (2B) Metahalloysite (3)	*5c* Illite (1) C-Vermiculite (2A) Montmorillonite (2B) Metahalloysite (3)	*5c* C-Vermiculite (2A)
Strongly weathered	6	*6a* Montmorillonite (2b)	*6b* Metahalloysite (3) Montmorillonite (2B)	*6c* Metahalloysite (3)	
Weakly weathered	7a				*7a* C-Vermiculite (2A) Illite (1)
Strongly weathered	7b				*7b* Silica (4) Metahalloysite (3)

NOTE: (1) The figure in italics (e.g. *5b*) in each box is genetic class No.
(2) The figure in brackets after the mineral name is the weathering stage of the mineral See Table 4.

Relation of Clay to Soil Structure

There is a marked difference in soil structure between yellow-grey and yellow-brown earths. Subsoils of yellow-grey earths have a hardpan with massive columnar structure while subsoils of most yellow-brown earths contain nutty aggregates resulting in an open structure more suited for root growth, drainage, and aeration. As may be seen from Table 1 clay contents of subsoils of these two groups are comparable and their platy clay minerals are also similar.

Yellow-grey earths may contain in their clay fraction various mixtures of illite, clay-vermiculite, montmorillonite, and hydrous micas. Yellow-brown earths contain similar constituents and some have appreciable meta-halloysite. Although the proportions of constituents vary appreciably between different genetic classes it is possible for certain yellow-grey earths to have essentially the same assemblage of platy clay minerals as some yellow-brown earths. This fact is illustrated in Table 1 by the Wharekaka soil of genetic class 2h, lab. no. 959C, from the B horizon of a yellow-grey earth, and the Kourarau soil, genetic class 5a, lab. no. 5882B, from the B horizon of a yellow-brown earth.

Differences in ionic conditions are not sufficient to account for the differences in soil structure since both soils have pH near 6, and per cent base saturation near 60. There is a significant difference in the ratio of exchangeable calcium to magnesium (a characteristic difference between the yellow-grey and yellow-brown earths), but since both ions are divalent the difference is unlikely to affect the degree of dispersion of the clays though higher magnesium may promote greater swelling of the expanding micas in yellow-grey earths.

These and other similar cases make it unlikely that the nature of the platy clay minerals is the cause of the difference in soil structure.

From consideration of subsoil structures it seems likely that colloids are in a dispersed condition in yellow-grey earths and aggregated in yellow-brown earths. This is supported by the fact that oriented aggregates for X-ray work are easily prepared from the clays (not deferrated) of yellow-grey earths, but not from clays of yellow-brown earths. Work by F. B. Hurst and G. M. Will (pers. comm.) showed that, for a number of South Island soils, amounts of free iron oxide and free alumina (estimated by extraction with sodium hydrosulphite and subsequent extraction with hydrochloric acid respectively) were each below 1·5% of the soil in yellow-grey earths and each above 1·5% in yellow-brown earths. It appears that higher amounts of oxides may contribute to the aggregation and improved structure of yellow-brown earths. Breakdown of feldspars also occurs at greater rate under weathering conditions of yellow-brown earths and fine particles of hydrous feldspar resembling allophane may assist in aggregate formation.

Aggregate formation in yellow-brown earths is apparently associated more with rainfall than with any other factor. Yellow-brown earths, for instance, are found on a variety of parent materials, and in regions of average mean temperatures ranging from 42°F to 57°F but not in regions of average annual rainfall much less than 35 in. In many localities yellow-grey earths

occur in low rainfall areas at the foot of hills while yellow-brown earths are found on similar parent material at higher altitudes and rainfall (Taylor, 1948), the transition occurring about the 35 in. rainfall regions.

GLEY PODZOLS *(Genetic class 8)*

The clay mineralogy of a single zonal gley podzol is indicated in Table 1. The effect of gleying which might perhaps have been expected to result in some montmorillonite has not done so. Apart from the presence of hydrous micas the relation of the clay mineralogy of this class to that of other zonal soils is not obvious from the single soil and more samples need to be examined.

INTRAZONAL SOILS

The nature of the primary minerals in the parent materials of many New Zealand intrazonal soils has a particularly important influence on the nature of the secondary minerals in the soils, and on the properties of the soils. The relation of the nature of the primary silicates to the mineral colloids has been discussed by Fieldes and Swindale (1954).

RENDZINAS *(Genetic class 11)*

Rendzinas are derived from calcareous rocks and argillaceous limestones. The soils may contain free calcium carbonate and tend to have high pH, high exchangeable calcium, and high per cent base saturation. The feature of the clay mineralogy of well-developed rendzinas is that their clay fraction consists predominantly of montmorillonite. This is illustrated by the results for two Arapohue soils listed in Table 1. Intrazonal soils of this class and of class 17 are included with zonal soils in Table 1 because like the latter they contain hydrous micas.

The mechanism of formation of montmorillonite from micaceous minerals and reasons for its stability in soils of high calcium content are discussed above in the section on montmorillonites under yellow-brown earths.

A less well-developed rendzina, the Kourarau soil from limestone, genetic class 11, Table 1, contains various hydrous micas including montmorillonite. This indicates that primary mica is the probable source of the montmorillonite.

All of the rendzinas listed contain quartz, and the Arapohue soils contain appreciable secondary quartz. Secondary quartz content is high in other New Zealand soils containing montmorillonite, for example, zonal soils of genetic classes 6a and 6b in Table 1. Secondary quartz content is also high in many New Zealand bentonites which also contain montmorillonite and calcite. The significance of this is not at present clear.

GLEY SOILS *(Genetic class 17)*

Results of examination of the clay of a single soil of this type are given in Table 1. It is likely that parent material would have a marked effect on the nature of the clay and that numerous soils of this type would

need to be examined in order to identify any common effects of the gleying process. As in the case of the gley podzol referred to above montmorillonite is absent.

YELLOW-BROWN PUMICE SOILS *(Genetic class 13)*

Yellow-brown pumice soils are derived from coarse rhyolitic pumiceous ash. The eruptions from which they are formed occurred in the Central North Island. The age of the parent material has been shown by radioactive carbon dating to be less than 5,000 years (Fergusson and Rafter 1953). The nature of the showers is discussed by Baumgart (1954). The principal primary minerals present are rhyolitic volcanic glass, feldspar, and quartz. Because of their youth they are little weathered. They contain 1 to 10% of inorganic clay that is amorphous to X-rays. As indicated in Table 2, clays from soils of this genetic class, 13, consist predominantly of members of the allophane series. This series was fairly fully treated by Fieldes (1955). A stable mineral-organic complex between humic material and alumina may be a factor in the relatively slow rate of decomposition of organic matter observed in these soils. Allophane and the mineral-organic complex is discussed below, under yellow-brown loams.

YELLOW-BROWN LOAMS *(Genetic class 14)*

Yellow-brown loams are derived from volcanic ash. Parent ash of many yellow-brown loams is andesitic, but it may be dominantly rhyolitic as in the case of soils from Tirau ash. The principal primary minerals of both andesitic and rhyolitic ashes are similar. They include considerable amounts of volcanic glasses and feldspars, and smaller but appreciable amounts of augite, hypersthene, hornblende, and magnetite. Magnetite is resistant to weathering. The other primary constituents weather during soil formation and because of their crystal structure their initial clay-size products of weathering consist of amorphous hydrous oxides of aluminium, iron, and silicon (Fieldes and Swindale, 1954). Volcanic glass, which is the major primary constituent, is relatively easily weathered and most of the clay fraction of yellow-brown loams is derived by the weathering of volcanic glass to allophane.

The clay fraction of yellow-brown loams thus consists principally of allophane (Taylor, 1933; Birrell and Fieldes, 1952). Fieldes (1955) has shown that amorphous hydrous oxides of aluminium and silicon are discrete as allophane B in the young yellow-brown pumice soils from volcanic ash. With increasing age they grow together to form allophane A in the yellow-brown loams. Allophane A is formed when very small particles of solid hydrous aluminium oxide are randomly cross-linked by tetrahedral silica. The resulting random structures are full of holes and this together with small particle-size leads to large surface areas and low bulk densities. The density of allophane is further reduced by the relatively large amounts of hydrous alumina it contains.

Soil Properties due to Allophane A

The size of particles of allophane in yellow-brown loams is truly colloidal (Birrell and Fieldes, 1952) and as allophane comprises 25% to

50% of the total of some soils, active gel formation would be expected at pH values remote from its isoelectric point. However, as shown by Birrell and Fieldes (1952) allophane remains flocculated over a wide range of pH values. It remains flocculated in the pH range of the soils. The reason for this is related to its structure. Hydrous silica (isoelectric pH value about 3) is weakly linked with hydrous alumina (isoelectric pH value about 7) so that at soil pH values between 5 and 7 each particle has both positive and negative sites and particles cohere readily. Because of the proximity of sites of opposite colloidal charge each field of attraction is, however, influenced by a weaker field of repulsion, and cementing properties of allophane are therefore not strong. Thus although the flocculated clays yield soils that are well-aggregated and have good drainage, the aggregates are friable and easily broken when dry. Rubbing when moist is apparently able to break weak linkages between silica and alumina so that the material yields in a manner and for a reason analogous to the yielding of wax near its melting point. This waxiness in consistency was observed by Taylor (1933) when he first reported allophane as the clay of a soil derived from Mairoa ash.

Because of its structure allophane is also able to retain both cations and anions, and the phosphate retention properties of the yellow-brown loams, particularly those with relatively low contents of hydrous iron oxides, are due largely to aluminous sites in the structure of allophane A.

Other Clay Constituents

Allophane B

As the parent material of yellow-brown loams is still actively weathering discrete freshly precipitated hydrous oxides of aluminium and silicon will be present in their clays. These are often in higher concentrations as allophane B or allophane AB (Fieldes, 1955) in topsoils, but in B horizons their content is low relative to allophane A, and detection is not easy.

Metahalloysite

In older soils from volcanic ash rearrangements of the silica and alumina of allophane A result in the formation of the sheet structure of metahalloysite (Fieldes 1955). Physical and colloidal properties of halloysite are quite different from those of allophane and soils from volcanic ash containing much metahalloysite are morphologically different from yellow-brown loams and are classed by Taylor (1948) as brown granular clays. Small amounts of metahalloysite are, however, present in the clays of topsoils classed as yellow-brown loams. The amounts seldom exceed about 5%. Metahalloysite is not active chemically compared with allophane and other amorphous colloids. Methalloysite is frequently the main constituent of the clays of yellow-brown loam deep subsoils which are older than corresponding upper horizons.

Hydrous Iron Oxides

The presence of considerable amounts of free hydrous iron oxides in many yellow-brown loams is indicated by their colour. Amounts of the

order of 10% are frequently found on silicate analysis of the clays, but clay of water-sorted ash may contain less than 1% and a clay from a Mairoa ash soil contained over 18% of iron as Fe_2O_3. DTA can differentiate between "pure" samples of freshly precipitated hydrous iron oxide before crystallisation, and various forms of hydrated oxides which have developed crystalline structure. DTA evidence concerning the form of iron at the concentration in these clays, however, shows no clear pattern except that older soils tending to brown granular clays contain lepidocrocite and goethite. The amounts of the various forms differ from soil to soil and in some the form is uncertain. The form of iron in these soils needs further investigation.

Mineral-organic Complex

Evidence of formation of complexes between humic material and alumina in volcanic ash soils is given by Fieldes (1955). These are present in different amounts in the topsoils of yellow-brown loams. Considerable amounts are present in topsoils of yellow-brown pumice soils. The presence of much mineral-organic matter is considered to indicate that weathering of the soil has occurred in the presence of the organic cycle. Low content of mineral-organic matter in the topsoil indicates that most of the weathering of the soil occurred at depth in the absence of organic matter. This may be a useful criterion of the past history of a volcanic ash soil, and an attempt is currently being made to use it to estimate extent of past erosion on soils used for pine forests to assist in mapping and assessing potential fertility.

Gibbsite

Because of the nature of the parent material, clays of yellow-brown loams are high in alumina. With advancing age silica combines with alumina to form first allophane A and then metahalloysite in which the silica:alumina molecular ratio is 2 : 1. Free alumina in excess of the amount required to combine with silica crystallises to gibbsite and gibbsite is often found in the clay of yellow-brown loams of advanced age whose parent material was relatively high in alumina.

Profile Differentiation

Considerable differences in the nature of clay in different horizons of volcanic ash soils are to be expected. Over long periods, variable mixing of showers of different ages could lead to variations in parent material, without showing clear evidence of different showers. Weathering processes differ with depth, and present-day topsoils have been derived from various levels according to the extent of erosion. Similar differences are possible for many soil classes but because of the nature of the ash and the intermediate weathering stage of yellow-brown loams the differences are readily detected in this class of soil.

Any yellow-brown loam developed from an ash-shower which developed a single vegetative cover without subsequent excessive erosion will have allophane AB, and mineral-organic complex in its topsoil; allophane A in its B horizon; and metahalloysite increasing with increasing depth.

If there has been considerable erosion, the clay of the topsoil is likely to be allophane A with appreciable metahalloysite in the B horizon.

Where mixed ash-showers occur many variations are of course possible, depending on the depth of each shower, the time for which it was exposed, and the nature of the processes. A Mairoa soil examined, for instance, had clay of its topsoil consisting of gibbsite and metahalloysite; clay of an underlying waxy pan consisting mainly of allophane A with small amounts of gibbsite, hydrous iron oxide, metahalloysite, and mineral-organic complex; and clay from an older ash shower in the subsoil which was mainly metahalloysite.

Notwithstanding the number of variables discussed here, it may be repeated that the properties of typical yellow-brown loams are dominated by their high content of allophane. Some properties which may be better understood from a knowledge of the nature of allophane have been mentioned here but much remains to be learned, particularly concerning anion and cation affinities and their distribution between the clay and the plant.

Soils from mixed parent materials including much ash have not been discussed here. These present special problems of classification.

BROWN GRANULAR LOAMS AND CLAYS *(Genetic class 15)*

Brown granular loams and clays of genetic class 15 are derived from andesitic parent material, which may be either andesitic volcanic ash or andesite.

Kaolin in the form of metahalloysite is the dominant clay mineral in weakly and strongly leached brown granular clays. Those derived from andesitic ash, such as the Hamilton clay loams of Table 2, contain mainly metahalloysite in the form of cylindrical tubes. They represent an advance in weathering stage beyond the yellow-brown loams which are derived from similar ash, and there is a corresponding advance in the nature of their clays from allophane to kaolin. Sequences illustrating these changes are described by Fieldes (1955). These soils may contain some allophane A particularly in their topsoils, and DTA gives evidence of the presence of some montmorillonite.

Strongly leached brown granular clays from andesite are illustrated by the Rangiuru clays of class 15b in Table 2. Their clay fractions are also dominantly metahalloysite, but they are shown by infrared evidence (Fieldes *et al.*, 1956) and DTA evidence (Fieldes, 1957) to have more orderly crystalline structure than the metahalloysite of brown granular clays from andesitic ash. Fieldes and Williamson (1955) have shown that particles of metahalloysite in Rangiuru soils from andesite are present as some tubes, some small plates, and numerous larger blocky particles probably pseudomorphous with feldspars from which they have been formed. Both the Hamilton and Rangiuru soils contain high amounts of iron. In the clay of the more weathered Rangiuru soil DTA gives clear evidence of the presence of lepidocrocite and goethite (Fieldes, 1957) which is in accordance with the tendency of hydrous oxides to form stable crystalline oxides with advancing weathering stage.

Under strongly podzolising conditions a podzol can form from andesitic tuff. The profile differentiation illustrated by the clays of the Tinopai soil (Table 2) resembles that of a zonal podzol, the Wharekohe soil (Table 1).

RED AND BROWN LOAMS *(Genetic class 16)*

Parent material of the red and brown loams is basalt. The relation of the nature of the clay fraction to primary minerals in soils derived from basalt has been discussed by Fieldes and Swindale (1954). The clay fractions of rapidly weathering soils derived from basalt in Cook Islands soils have been shown by Fieldes *et al.* (1952) to contain unusual forms of amorphous hydrous oxides.

Of New Zealand soils from basalt examined, the Middlehurst soil (Table 2) is the least mature. Its clay was largely amorphous to X-rays, had high apparent cation exchange capacity, and was shown by electronmicrography to contain much ultra-fine colloidal material. Because of its form the ultra-fine colloidal material is thought to be largely amorphous hydrous alumina. The clay also contained some hydrous mica and possibly some goethite and palagonite. Because of its general lack of structure and failure to show marked heat effects in DTA its nature is somewhat obscure.

Other soils derived from basalt, genetic class 16a to c, are shown by DTA to contain considerable amounts of gibbsite, variable amounts of kaolin and evidence of phosphated oxides. Less mature soils, classes 16a and b, may also have strongly held organic matter in the form of mineral-organic complex.

With increasing maturity from class 16a to 16c there is a marked increase in the degree of crystallinity and particle size of the hydrous oxides. Clays of the least mature soils are generally amorphous to X-ray diffraction, and particle size shown by electron micrographs is very small. With increasing maturity particle size increases and increase in crystallinity is shown by the appearance of increasingly sharp lines in X-ray patterns. These correspond to crystalline gibbsite, goethite, anatase, and kaolin. The mature soils from basalt also give DTA evidence of phosphated oxides and lepidocrocite. The degree of crystallinity of clays from mature red and brown loams is, however, considerably less than that of certain mature tropical soils from basalt. (Fieldes and Williamson, 1955).

SUMMARY OF DOMINANT CLAY CONSTITUENTS

The pattern of dominant clay minerals in New Zealand soils may now be summarised in terms of the genetic classification.

Zonal Soils

Clay minerals at early weathering stages (genetic classes 1 to 3) are principally weathering products of micas. Later stages contain in addition amorphous products of feldspathic weathering and soil structure improves. Dominant clay minerals are as follows:

Genetic class 1, brown-grey earths (av. mean temp. 47°F, mean ann. rainfall 12 to 25 in.). Mainly weakly hydrated mica with some illite and clay vermiculite. Clay content of topsoils 5% to 11%.

Genetic class 2, yellow-grey earths (52°F., 20 to 40 in.). Mainly illite with different amounts of clay-vermiculite, montmorillonite, and interlayered hydrous mica intermediates. Clay content of topsoils 15% to 19%.

Genetic class 3, soils transitional between yellow-grey earths and yellow-brown earths. Clay minerals similar to yellow grey earth and yellow-brown earth groups. Clay content of topsoils 15% to 20%.

Genetic class 4, weakly weathered yellow-brown earths (42°F 35 to 70 in.). Illite and clay-vermiculite are dominant with some montmorillonite and interlayered hydrous micas. Clay content of topsoils 12% to 16%.

Genetic class 5, moderately weathered yellow-brown earths (52°F, 40 to 100 in.). Most contain considerable illite. Weakly leached members, genetic class 5a, contain also considerable montmorillonite and some clay-vermiculite, and interlayered hydrous micas. With increased leaching, genetic classes 5b and 5c montmorillonite is less or absent and metahalloysite is common. Clay content of topsoils is 16% to 28%.

Genetic class 6, strongly weathered, yellow-brown earths (57°F, 50 to 100 in.). Weakly leached members, genetic class 6a, contain much montmorillonite together with illite, clay-vermiculite and interlayered hydrous micas. In more leached members genetic classes 6b and 6c, metahalloysite is dominant with some montmorillonite and interlayered hydrous micas but illite and clay-vermiculite are not detected. Clay content of topsoils 22% to 46%.

Genetic class 7a, weakly weathered, moderately podzolised yellow-brown earth (47°F, approx. 200 in.). Illite and clay-vermiculite are dominant resembling genetic class 4 and the weakly podzolised Renata soil. Clay content of topsoil 15%.

Genetic class 7b, podzol. (57°F, approx. 80 in.). Clay of topsoil of strongly weathered podzol contains mainly secondary quartz with some metahalloysite and primary quartz. Metahalloysite increases in B horizon. Clay content of topsoil 14%, subsoil 71%.

Intrazonal Soils

The nature of these soils is affected by the special nature of their parent materials and processes and the nature of their clay fraction varies accordingly. Dominant clay minerals or mineral colloids are as follows:

Genetic Class 11, rendzinas, from calcareous parent material. Mainly montmorillonite. In immature members illite and other hydrous micas are present.

Genetic class 13, yellow-brown pumice soils. Allophane is dominant. In younger members the form is allophane B, in older members it grades to allophane AB. Clay content of topsoils 3% to 9%.

Genetic class 14, yellow-brown loams, from rhyolitic and andesitic volcanic ash. Dominantly allophane A with some metahalloysite. Clay content of topsoils 13+% to 20+%.

Genetic class 15, brown granular clays, from andesitic parent material. Dominantly metahalloysite. Gibbsite, lepidocrocite, goethite, quartz, and montmorillonite may be present. Topsoil clay of a related podzolised soil contains mainly primary and secondary quartz. Clay content of topsoils 15% to 43%.

Genetic class 16, red and brown loams, from basaltic parent material. *Immature* members contain amorphous hydrous oxides of aluminium, iron and titanium. *Semi-mature* members contain mainly fine crystalline gibbsite with considerable metahalloysite, some fine particle size anatase, goethite and boehmite and some amorphous material, while *mature red and brown loams* contain crystalline oxides of large particle size and consist predominantly of gibbsite with goethite, lepidocrocite, anatase, and metahalloysite.

CONCLUSION

The results presented demonstrate the satisfactory correlation between the nature of the clays and Taylor's (1948) genetic classification, for a large number of genetic classes. Results for any particular soil type become much more significant when seen in relation to those of other soils through this systematic classification.

The results confirm the fundamental basis of the classification and illustrate the manner in which it may assist and simplify projects concerned with a wide range of New Zealand soils.

Assemblages of the 22 constituents identifiable in New Zealand soil clays vary markedly from class to class. Characteristic properties of the various soil classes can be correlated to the type of mineral colloids they contain. There are pronounced differences between the mineral colloids of the intrazonal soils which consist of amorphous hydrous oxides and crystalline materials formed from them by aggradation.

There is a wide distribution of amorphous colloids or crystalline colloids of very fine particle size among intrazonal soils of New Zealand. This is due to temperate weathering conditions. As mentioned above, for instance, clays of mature soils from basalt in the tropics have considerably larger crystalline particles than corresponding New Zealand clays.

For soils developed on similar parent material, increase in average mean temperature increases the amount of clay and advances its stage in the weathering sequence of Fieldes and Swindale (1954). Variations in rainfall and conditions of leaching cause variations in the course of weathering.

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A NEW ZEALAND PHYTOCHEMICAL SURVEY—PART 3

THE FERNS AND FERN ALLIES

By R. C. Cambie, Department of Chemistry, University of Auckland; B. F. Cain and S. La Roche, British Empire Cancer Campaign Society Laboratory, Cornwall Hospital, Auckland.

(Received for publication, 30 June 1961)

Summary

Two species of the order Psilopsida, 9 of the order Lycopsida, and 63 of the order Filicopsida have been examined for the presence of alkaloids, leucoanthocyanins, saponins, and triterpenes or steroids. Alkaloids are present in *Lycopodium* species but absent in all others with the possible exception of *Asplenium* and *Marattia*. A number of ferns contain leucoanthocyanins and a limited number saponins, but triterpenes or steroids appear to be absent.

Introduction

In addition to gymnosperms and dicotyledones examined in this survey (Cain, Scannell and Cambie, 1961; Cambie, Cain and La Roche, 1961) ferns and fern allies have been investigated for the presence of alkaloids, leucoanthocyanins, saponins, and triterpenes or steroids. The results of chemical testing on fresh material or herbarium samples of 74 species are reported in Table 1.

The methods used in testing follow those described in detail in Part I. The sequence of families and species in Table 1 follows that in Allan (1961).

Abbreviations used in Table 1 for plant part are as follows: Fr = fronds; L = leaves; H = whole plant; Rh = rhizomes; St = stems.

All other abbreviations follow those used in previous parts.

Results and Discussion

The consistency of positive alkaloid tests in members of the Lycopodiaceae, especially where fresh material has been used, confirms these as potential sources of alkaloids. In a survey of the Lycopodiaceae, Manske (1955) has isolated a number of alkaloids from species of the Northern Hemisphere but because of the low yields obtained in most cases, structures of the majority of compounds isolated are still unknown. Three species found growing in New Zealand have also been investigated and details are included in Table 1. All New Zealand species could well bear further investigation with the use of modern techniques for the separation and handling of small quantities.

Leucoanthocyanins appear to be consistently found in the families Blechnaceae, Dryopteridaceae, Gleicheniaceae, and Hymenophyllaceae. In addition they were found in the families Adiantaceae, Cyatheaceae, Davalliaceae, Dicksoniaceae, Grammitidaceae, Osmundaceae, Pteridaceae, Schizaeaceae, and Thelypteridaceae.

TABLE 1

Systematic Name of Plant	Maori Name or Popular Name	Plant Part	Locality	Month Collected	Herbarium No.	Alkaloid Test M	Alkaloid Test D	LA	Sap	LB
PSILOPSIDA										
PSILOTACEAE										
Tmesipteris tannensis Bernh.		Fr	Herbarium	—	70648					—
Psilotum nudum Palisot-Beauvois		Fr	Kermadec Is.	June		—	—(1)			—
LYCOPSIDA										
LYCOPODIACEAE										
Lycopodium australianum Allan	fir club-moss	L	Herbarium	—	70646		—	—	—	—
Lycopodium varium R. Br.	nodding club-moss	L, St	Herbarium	—	70649	—	—	—	—	—
		Rh	„	—	„	—	+	—	—	—
Lycopodium billardieri Spring.	iwatuna	L	Herbarium	—	70652	—	—	—	—	—
Lycopodium laterale R. Br.	bog club-moss	H	Herbarium	—	70650	—	+	—		—
Lycopodium cernuum L.	creeping club-moss	L	Huia	March	46482	+	+(2)	—	—	—
Lycopodium deuterodensum Herter	puakarimi	L	Herbarium	—	70651	+	+(3)	—	—	—
Lycopodium fastigiatum R. Br.	alpine club-moss	H	National Park	October	46547	+	+(4)	—	—	—
Lycopodium scariosum Forst. f.	creeping club-moss	L	Huia	March	46480	—	+		—	—
Lycopodium volubile Forst. f.	waewaekoukou (antler-fern)	L	Huia	March	46477	—	+	—		—
FILICOPSIDA										
MARATTIACEAE										
Marattia salicina Smith	para	L	Huia	March	70659	+	+	—	—	—
	(horseshoe-fern)	St	„	„			—	—	—	—
		R	„	„			—	—	—	—

OSMUNDACEAE										
Todea superba Col.	heruheru (Prince of Wales feather)	Fr	National Park	Jan.		—	—	+	—	—
Todea hymenophylloides A. Rich	heruheru (single Prince of Wales feather)	Fr	National Park	Jan.	46517	—	—	+	—	—
SCHIZAEACEAE										
Lygodium articulatum A. Rich.	mangemange	L	Huia	March		—	—			—
Schizaea dichotoma Smith	kauri-fern	H	Mayor Is.	April		—	—	+	—	—
GLEICHENIACEAE										
Gleichenia circinata Swartz	waewaekotuku	H	Auckland	Sept.		—	—	+	—	
Gleichenia circinata Swartz var. *alpina* Cheesem.	alpine umbrella-fern	H	National Park	Jan.		—	—	+	+	—
		H	„	Oct.	50059	—		+	+	—
Gleichenia cunninghamii Heward ex Hook.	waekura (bush umbrella-fern)	L	National Park	Oct.	50057		—	+	+	—
		Rh	„	„			—	+	+	—
HYMENOPHYLLACEAE										
Hymenophyllum flabellatum Labill.	fan-leaved filmy fern	H	Herbarium	—	70663	—		—	—	—
Hymenophyllum dilatatum Swartz	matuamauku	L, St	Herbarium	—	70653	—		+	—	—
Hymenophyllum rarum R. Br.	thin-leaved filmy fern	H	Ohakune	Oct.	50081 & 50093	—	—	+	—	—
Hymenophyllum sanguinolentum Swartz	piripiri (scented filmy fern)	H	National Park	Oct.	50117 & 50120	—	—	+	—	—
Hymenophyllum demissum Swartz	irirangi (carpet fern)	L	National Park	Nov.	50091	—	—	—	—	—

([1])Swanholm, St. John, and Schuer (1959) record negative alkaloid tests.
([2])Swanholm, St. John and Schuer (1959) record weak positive alkaloid tests. Marion and Manske (1948) record the presence of the alkaloids, cernuine, nicotine, and a base (L 33).
([3])Manske (1953) records the presence of the alkaloid, lycopodine and bases (L34) and (L35) from *L. densum* (=*L. deuterodensum* Herter).
([4])Marion and Manske (1944) record the presence of the alkaloids, lycopodine, nicotine and bases (L13), (L18), (L19) in *L. clavatum* L.) (=*L. fastigiatum* R. Br.) of American origin. Achmatowicz and Uzieblo (1938) record the presence of the alkaloids lycopodine, clavatine and clavatoxine from *L. clavatum* L. of European origin.

TABLE 1—*continued*

Systematic Name of Plant	Maori Name or Popular Name	Plant Part	Locality	Month Collected	Herbarium No.	Alkaloid Test M	Alkaloid Test D	LA	Sap	LB
Hymenophyllum pulcherrimum Col.	tufted filmy fern	L	National Park	Jan.		—	—	+		—
		Fr	Mt. Egmont	Dec.		—	—			
Hymenophyllum ferrugineum Colla.	rusty filmy fern	H	Herbarium	—	70661	—	—	+	(+)	
Hymenophyllum revolutum Col.		H	Herbarium	—	225	—	—	—	(+)	
Trichomanes reniforme Forst. f.	raurenga (kidney-fern)	L, St	Herbarium	—	70669	—	—	+	+	—
DICKSONIACEAE										
Dicksonia squarrosa Swartz	wheki	L	Auckland	Sept.		—	—		—	
		St	,,	,,		—	—	+		—
Dicksonia fibrosa Col.	kuripaka	L, St	Auckland	Sept.			—	+		—
Dicksonia lanata Col.	stemless tree-fern	Fr	Herbarium	—	70660			—	—	—
CYATHEACEAE										
Cyathea dealbata Swartz	ponga	L	Waitakeres	Jan.		—	—	—	—	—
		St	,,	,,		—		—	—	—
Cyathea medullaris Swartz	mamaku	L	Auckland	Sept.		—	—	—	—	—
		St	,,	,,		—	—	+		—
Cyathea milnei Hook. ex Hook. f.	Milne's tree fern	St	Kermadec Is.	June		—	—	—	+	
Cyathea kermadecensis W.R.B. Oliver		St	Kermadec Is.	June		—	—	—	+	
Cyathea smithii Hook. f.	whe	H	Kaimais	May	50079	—	—	+	—	
		Fr	Mt. Egmont	Dec.		—	—	—	—	—
Cyathea colensoi Domin.	grove-fern	Fr	Herbarium	—	70668	—	—	—	—	—

| | | |

TABLE 1—*continued*

Systematic Name of Plant	Maori Name or Popular Name	Plant Part	Locality	Month Collected	Herbarium No.	Alkaloid Test M	Alkaloid Test D	LA	Sap	LB
Histiopteris incisa J. Smith	matata (water fern)	L	Waitakeres	Jan.		—	—	—	—	—
Pteris tremula R. Br.	tarawera (trembling bracken)	L	Huia	March		—	—	—	—	—
		St	„	„		—	—	—	—	—
		Rh	Ohakune	Oct.	50085	—	—	—	—	—
ASPLENIACEAE										
Asplenium flabellifolium Cav.	necklace-fern	H	Herbarium	—	70657	—	—	—	+	—
Asplenium lucidum Forst. f.	huruhuruwhenua (shining spleenwort)	L	Auckland	Sept.		—	—	—	—	—
		St	„	„		—	—	—	—	—
Asplenium falcatum Lam.	petako	L	Herbarium	—	70658	—	—	—	—	—
Asplenium bulbiferum Forst. f.	mouki	L, St	Auckland	Sept.		—	+	—	—	—
Asplenium bulbiferum Forst. f. var. *tripinnatum* Hook. f.		L, St	Auckland	Sept.		+	+			
Asplenium hookerianum Col.	petako (lance-leaved spleenwort)	L, St	Herbarium	—	363	—		—	—	—
Asplenium flaccidum Forst. f.	makawe	H	Wade River	April	46509			—	—	—
		H	Taupo	Oct.	46541	—	—	—	—	—
BLECHNACEAE										
Doodia media R. Br.	pukupuku	L	Auckland	Aug.		—	—	+	(+)	—
		St	„	„		—	—	+	—	—
Blechnum fraseri Luerss.	Frazer's fern	L, St	Huia	March		—	—	+		—
		L	Waitakeres	Dec.		—	—	+	—	—
		St	„	„		—	—	+		—
		Rh	„	„		—	—	+	—	—
Blechnum filiforme Ettingshausen	panako (thread-fern)	L	Huia	March		—	—	+	—	—
		St	„	„		—		+	—	
		Rh	Waitakeres	Jan.		—	—	+	—	—

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Few families were found to contain saponins, Gleicheniaceae being the only one in which such compounds were consistently present. However, because of the few samples tested, the positive saponin tests cannot be considered as diagnostic for taxonomic purposes. Only one fern, *Rumohra hispida*, gave a positive Liebermann-Burchard test and it would appear that triterpenes are not generally present in the ferns.

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THE WEATHERING OF ARAMITE RESIDUES ON APPLES

By P. J. Clark, Dominion Laboratory, Department of Scientific and Industrial Research, Wellington.

(Received for publication, 11 August 1961)

Summary

Apple trees were sprayed with Aramite at different periods before harvest and the amount remaining on the fruit was determined at intervals during the remainder of the season. The residue was reduced significantly by rain but a period of seven weeks between spray and harvest was insufficient to allow the level to fall to the required tolerance of zero.

Introduction

Aramite or 2-(*p*-tert-butylphenoxy) isopropyl 2-chloroethyl sulphite is a commonly used acaricide. The New Zealand Food and Drug Regulations fix a limit of Nil for residues of Aramite on fruit, based on the U.S.A. findings that the compound is carcinogenic. A study has therefore been made of the natural weathering of Aramite residues on apples. Various workers (Gunther *et al.* (1951); Watson (1956); and Brokke *et al.* (1958)), have developed methods for the determination of small amounts of Aramite, but in the present study the method of Mills and Sheehan (1959) has been used with minor modifications. In principle the method depends upon liberating ethylene oxide from Aramite by heating with alkali. The ethylene oxide is hydrolysed by acid to ethylene glycol which is oxidised by periodic acid to formaldehyde. This is reacted with acetylacetone and ammonium acetate to form a yellow condensation product the intensity of which is measured spectrophotometrically.

Method

The apparatus as described by Mills and Sheehan (1959) was used except that the scrubber tube was replaced with one consisting of a fine glass spiral wound round the central tube. This was found to give a more consistent bubbling rate and a longer period for contact between vapour and liquid. The oil bubbler was also omitted and replaced by a soap-bubble flow gauge, located between the surge tank and the sulphuric acid. The gas flow was adjusted to between 4 ml and 6 ml per minute by introducing a bypass into the surge chamber whereby constant pressure was maintained, excess nitrogen escaping through a column of water.

Three plots of apple trees at the research orchards at Earnscleugh and at Nelson were sprayed with Aramite (25% wettable powder at 1 lb/100gal) at a time estimated to be from seven to eight weeks before harvest. Additional applications were made to the second and third plots two weeks later, and to the third plot four weeks later. Samples of apples were taken from the plots immediately after spraying, and at fortnightly intervals until harvest. Control samples from unsprayed trees were taken at the same times. The treatment schedule and dates of picking are shown in Table 1.

TABLE 1—Treatment Schedule for Apples

Treatment Number	Apple Plot A	B	C	Earnscleugh Cox	Nelson Delicious Plot A only	Jonathan	Sturmer
1	S&P*	S	S	11.1.60	28.1.60	8.2.60	7.3.60
2	P	S&P	S	25.1.60	8.2.60	22.2.60	21.3.60
3	P	P	S&P	8.2.60	22.2.60	7.3.60	4.4.60
4	P	P	P	22.2.60	7.3.60	21.3.60	19.4.60
5	P	P	P	29.2.60	21.3.60	28.3.60	26.4.60

*S = spray; P = picked.

Not less than six whole apples were shaken with 100ml of benzene for ten minutes. The benzene was decanted, dried with sodium sulphate and a 10 ml aliquot transferred to the reaction tube and evaporated on a rotary evaporator to 3 ml at a temperature not exceeding 25°C. The procedure as described by Mills and Sheehan (1959) was then followed.

Standard curves with Aramite (obtained from Naugatuck Chemical Division, U.S. Rubber Co.) were prepared each week, and when any of the reagents was renewed it was found that there was some change in the standard curve with time and that the changes were more pronounced in the early periods after the preparation of the acetyl-acetone reagent.

RESULTS AND DISCUSSION

Recovery of Aramite after the addition of known amounts in benzene to lots of six apples showed an average of 104% (Table 2). Control samples showed no Aramite.

TABLE 2—Recoveries of Aramite from Apples

Aramite Added mg	Aramite Found mg	Recovery %
0·25	0·26	
0·25	0·24	101
0·25	0·26	
0·5	0·48	
0·5	0·52	99
0·5	0·48	
0·75	0·78	
0·75	0·81	107
0·75	0·82	
1·0	1·12	
1·0	1·10	110
1·0	1·09	
1·5	1·60	
1·5	1·58	103
1·5	1·44	

As spraying and picking were carried out during a period of active growth and of increase in size of the fruit, the results in Table 3 have been calculated as the weight of Aramite per apple, based on the average figures for 3 replicate determinations carried out on at least 6 apples each. Rainfall figures have been included in the Tables and represent the amount of rain (in inches) between the picking periods in each locality.

TABLE 3—Aramite Residues on Apples

Variety	Treatment Number	Plot A		Plot B		Plot C		Rainfall Between Treatments (inches)
		Weight (g/apple)	Aramite (mg/apple)	Weight (g/apple)	Aramite (mg/apple)	Weight (g/apple)	Aramite (mg/apple)	
	1	44	0·091	—	—	—	—	
								0·41
	2	65	0·084	58	0·145	—	—	
								1·38
Cox	3	84	0·069	82	0·134	79	0·171	
								0·77
	4	94	0·043	86	0·097	75	0·187	
								0·00
	5	93	0·062	93	0·118	79	0·177	
	1	80	0·092	—	—	—	—	
								0·45
	2	96	0·072	84	0·139	—	—	
								0·00
Jonathan	3	94	0·070	89	0·143	95	0·192	
								2·53
	4	96	0·055	94	0·104	89	0·106	
								1·68
	5	118	0·057	109	0·123	100	0·103	
	1	94	0·104	—	—	—	—	
								2·53
	2	92	0·070	99	0·172	—	—	
								1·83
Sturmer	3	105	0·075	115	0·166	105	0·232	
								0·27
	4	116	0·069	112	0·143	120	0·287	
								0·00
	5	112	0·054	115	0·130	113	0·301	
	1	62	0·067					
								2·86
	2	93	0·058					
								0·45
Delicious	3	107	0·027					
								0·00
	4	100	0·022					
								2·53
	5	96	0·042					

In a mathematical study of the results it was assumed that the amount of Aramite on an apple would vary about $na-rb$ where n is the number of sprayings, a the amount of Aramite put on at each spraying, r the inches of rainfall since spraying, and b the amount of Aramite washed off by

each inch of rain. For each type of apple *a* and *b* were calculated and also the number of inches of rain per Aramite spray that would be required to wash off the Aramite. The results are shown in Table 4.

TABLE 4—Mathematical Examination of Residues

	Cox	Jonathan	Sturmer	Delicious
Aramite sprayed on mg/spray/apple (*a*)	0·069	0·061	0·103	0·061
Aramite washed off mg per inch of rain (*b*)	0·010	0·007	0·010	0·005
Rain required to remove one spray of Aramite (inches)	7	9	10	12
Level of Significance % (Tests hypothesis that *b* is different from zero)	1	10	0·1	10

It appears that approximately nine inches of rain would be required to wash off one spray of Aramite, and this is based upon the assumptions that the amount washed off is proportional to the amount of rain, and that later rains continue to wash off as much as earlier rains. It is most unlikely that such conditions would obtain, and the period of retention of Aramite on the apples would therefore be considerably longer.

An alternative model in which the spray removed was proportional to the time was also examined. This showed a reduction of 0·0038 mg Aramite per week but did not fit the data as well as did the rain model.

In Table 5 are shown the amounts of Aramite remaining on the apples at the time of final harvest, calculated as parts per million. These figures show that it is not possible to meet the requirements of the Food and Drug Regulations on the four varieties tested with even one spraying with Aramite applied seven weeks before harvest.

TABLE 5—Aramite Residues at Final Harvest as Parts per Million on Apples

	Aramite p.p.m.			
Apple Plot	Cox	Jonathan	Sturmer	Delicious
A	0·7	0·5	0·5	0·4
B	1·3	1·1	1·1	
C	2·2	1·0	2·7	

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AN INFESTATION OF WOOD BY *Bankia australis* Calman WITH A REVIEW OF THE ROLE OF WOOD IN SHIPWORM DIET AND ENVIRONMENT

By D. E. HURLEY, New Zealand Oceanographic Institute, D.S.I.R., P.O. Box 8009, Wellington, New Zealand.

(Received for publication, 3 August 1961)

Summary

A ship's wooden guardrail, lost near Cape Campbell in Cook Strait, New Zealand, during a storm in July 1960, was recovered in April 1961, heavily infested by *Bankia australis* Calman. It is considered that infestation must have occurred at a depth of 70 fathoms and the possibility is discussed that infestation sources occur naturally at that depth, not necessarily in wood. Arising from this, the necessity of wood for food and protection is discussed and questioned.

INTRODUCTION

In April 1961, a Wellington fishing boat trawled up a section of ship's guardrail from 70 fathoms of water approximately 20 miles east of Cape Campbell Lighthouse. This rail was identified by its dimensions and attached iron stanchions as being from the Union Steam Ship Company of New Zealand's vessel, T.E.V. *Rangatira.*

The guardrail was lost overboard on the night of 26 July 1960, during a southerly gale and head seas while the *Rangatira* was on passage from Wellington to Lyttelton. "At 2315 hours that night, in a position approximately 087° 13·3 miles from Cape Campbell Lighthouse, *Rangatira* struck a particularly heavy sea which washed overboard the guardrail under discussion from her port bow (abreast No. 1 hatch) into a charted depth of 71 fathoms. *Rangatira* was able to fix her position at 2345 hours that night when Cape Campbell bore from her 292° distant 9·7 miles. The discrepancy between the position where *Rangatira* lost her guardrail and the place it was found in a trawl may be accounted for by the fishing trawler concerned passing through the former point whilst trawling on an easterly course, or reach, that took her approximately 20 miles eastward of Cape Campbell, where her net was landed." (Pers comm., Chief Marine Superintendent, Union Steam Ship Company of New Zealand.)

The position at which the rail was found may have also been affected by drift during the period it was settling.

There is no doubt about the identity of the rail; it and the attached stanchions were distinctive in size and shape.

DESCRIPTION

The wooden part of the rail was of Australian spotted gum hardwood (*Eucalyptus maculata* Hook), 13 ft 16 in. long, 6 in. wide and 2 in. deep, with rounded edges, and attached to metal stanchions at four points. It

had been heavily attacked by teredo or shipworm, which had eaten through the rail on each side of the stanchion bases leaving only remnants of wood bolted to the stanchions, the largest remnant being only 9 in. long. This last length (Fig. 1) had retained its external shape unaltered except where the missing piece had fallen out. Only pallet holes on the surface indicated the inner burrows beneath, and traces of the original paint and varnish were still present. All four pieces recovered appeared to have been protected to some extent from teredo by the metal base plates of the

Photo: H. D. O'Kane

FIG. 1—Side and bottom view of remnant of guardrail showing relatively unharmed end protected by stanchion base and brass end-cap (removed). Note (*top*) teredo burrows running vertically, perpendicular to the grain; and (*bottom*) traces of paint around stanchion base and varnish, also entrances of burrows slightly larger than pin-head size.

stanchions, and the larger piece was further protected by a brass end cap. The stanchions were in surprisingly good condition considering their period in the water with little trace of damage to the original paint except for slight blistering due to anaerobic bacterial corrosion.

The most spectacular feature of the wood was the intensity of infestation (Fig. 2.) Where the wood had crumbled away, the burrows were

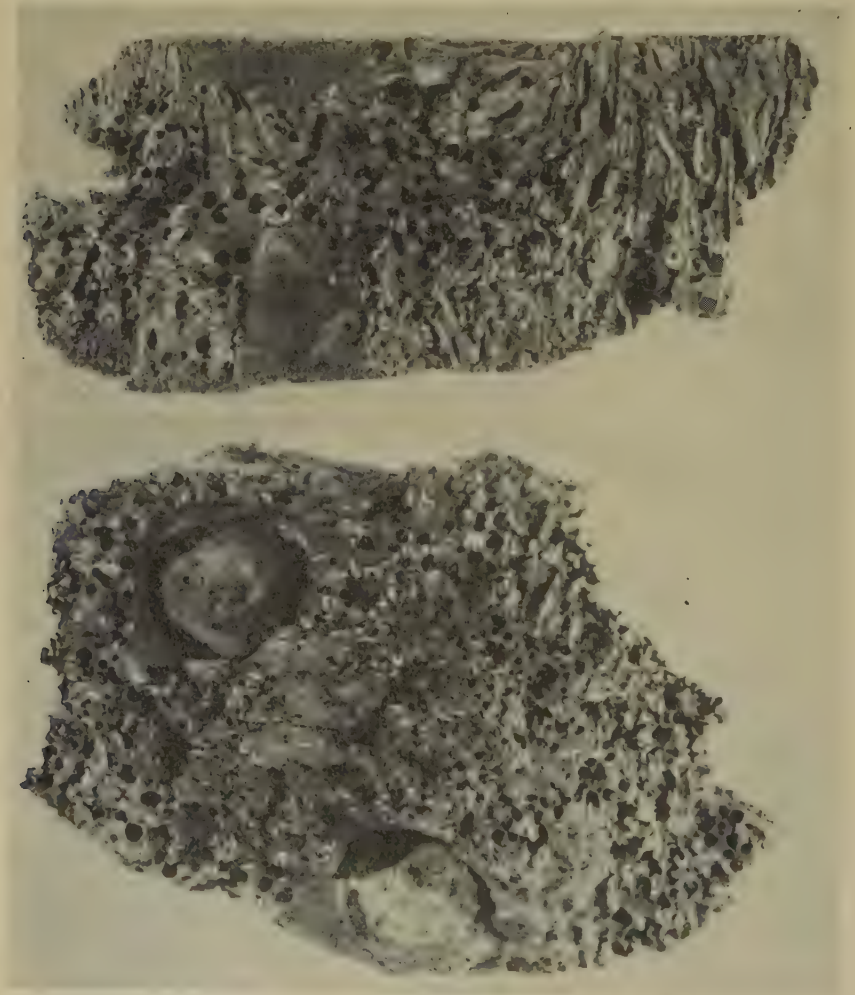

Photo: H. D. O'Kane

FIG. 2—*Top:* Vertical cross-section showing (*right*) heavy concentration of vertical burrows in area of unprotected surface, and (*centre*) burrows turning horizontally to run with grain where the surface has been protected from settling. *Bottom:* Horizontal cross-section showing general intensity of burrows around counter-sunk metal bolt-heads (originally protected by wooden plugs). These are natural cross-sections, not all in the same plane, formed by the adjacent heavily-burrowed wood falling away.

found to run vertically right across the depth of the rail giving it a honeycombed appearance. Pallets and shells remaining in the wood indicated that the species concerned was *Bankia australis* Calman (Calman, 1920). The direction of the burrows was most unusual; with the exception of a few small areas, they ran through the 2 in. thickness perpendicular to the grain of the wood (Fig. 1, top).

The author can suggest only one reason for this. That is, that the greatest settling of larvae took place more or less simultaneously and the large numbers of larvae entering the wood and growing down together at the same rate were prevented by the closeness of their neighbours from turning their burrows parallel to the grain as is their custom – teredo will not break through neighbouring burrows. The surface on which most larvae would settle would be the widest surface available and would dictate the direction of the greatest number of burrows. Confirmation of this can be seen in Fig. 2 (top) where the presence of a stanchion base has prevented settling and the nearest teredo have taken advantage of unburrowed wood alongside to turn at least partially along the grain. The thickness of the wood along the direction of burrowing has prevented most of the animals from exceeding 2 in. in length. In itself, the density of burrows has probably been sufficient to cause the riddled portions of wood to fall away but final disintegration may well have taken place while the wooden husk was being dragged along the bottom in the trawl-net.

DISCUSSION

Occurrence of Teredo at Depth

Few records are available of teredo living at depth. Anderson (1872) mentions teredo damage to cables at depths of 1,200 fathoms. Roch (1940), in a paper which is not available to the author, records *Teredo utriculus* from depths as great as 3,500 metres in the Mediterranean. (This probably refers to Jona, 1913.)

Edmondson (1955) submerged test-blocks in shallow water one mile off the coast of Hawaii at intervals from the surface to a depth of about 12 fathoms. "After three months . . . blocks at a depth of 25 feet were badly damaged by teredos, those at 50 and 75 feet were riddled. The principal species responsible for the destruction was *Teredo milleri,* the common teredo in the inshore waters about the island. It was observed that a block at a depth of 75 feet was attacked by eight to 10 times the number of individual teredo as attacked the block at a depth of 25 feet. Especially was the deeper block infested by small to medium-sized shipworms, whereas the superficial block showed infestation by fewer, but much larger, teredos."

According to Edmondson, *Eucalyptus maculata* in Hawaiian waters was heavily attacked and usually riddled by teredos in Hawaiian tests. There is, therefore, nothing unusual in the guardrail not resisting attack. Parenthetically, it might be noted that hardness or strength of wood is

seldom a deterrent to marine borers: those woods which show resistance usually contain notably large quantities of silica, tannins, alkaloids, oils, acids, or resins or other gummy substances.

The difference between possibility of infection one mile offshore in 75 ft and 13 miles offshore in 70 fathoms is considerable when discussing an animal usually associated with shallow depths and shoreline infestation sources. The question immediately posed by the *Rangatira* rail is, where did the teredo larvae come from?

Possible Sources of Infestation

The rail would not have been infested before being lost overboard. If it had floated for any length of time at the surface it could have been infested then, but according to advice from the New Zealand Forest Service, the weight of air-dry spotted gum with a 12% moisture content is approximately 63 lb per cu. ft. Since that of sea-water is approximately $64\frac{5}{8}$ lb per cu. ft., the wood is unlikely to have been buoyant and any slight buoyancy is not likely to have been enough to counteract the weight of the attached metal stanchions and brass fittings.

Infestation of the rail at the surface requires the presence of large numbers of pelagic *Bankia* larvae 13 miles offshore. In that event, the intensity of infestation would seem to demand a piece of wood riddled with spawning teredo floating fortuitously nearby. More probably, the degree of infestation and the lack of burrow turning suggest a source on the bottom alongside the rail's final settling position. If so, this might perhaps have been an adjacent piece of wood, infested at the surface and subsequently waterlogged to sink to the bottom carrying with it a breeding population of teredo; otherwise, one must postulate a swarm of larvae carried there from surface or shallow-water-spawning adults, which seems unlikely at this depth and distance offshore. The former would seem more probable. Edmonson's point that infestation was greater at 75 ft than nearer the surface also suggests that open water infestation sources are most likely to be on the bottom. Doochin and Walton Smith (1951) corroborate the tendency for intensity of attack to increase from the surface downwards, but associated it with circumstances demonstrated by Isham *et al.* (1951) showing that larvae have a slight negative buoyancy and tend to sink passively whenever ciliary activity ceases. With regard to the rail, it is difficult to imagine a set of such intensity being caused by surface spawn settling on the bottom. Rather, one would expect surface larvae to become widely dispersed during sinking.

Yet, if this is an example of bottom infestation, one wonders if there is sufficient wooden debris at 70 fathoms 13 miles offshore to support breeding populations at other than very occasional distances apart. Is it possible, then, that teredo at that depth normally exist by burrowing into some other material – algal holdfasts, for instance (which again would have to be fortuitously sunken ones) or perhaps sandstone or mudstone?

Necessity of Wood for Protection

Is wood necessary for protection of shipworm?

The author knows of no records of *Bankia* or *Teredo* as a rock-borer. There are, however, records of teredo burrowing, which imply growth and possibly breeding, in materials other than wood. Anderson (1872) reported that "teredo of all kinds" caused damage and failure to cables. One species was known to bore right through to the core but only in shallow water while another species destroyed the hemp in a few months and was then content to fix itself upon the gutta-percha and remain there. Cables had been recovered from 1,200 fathoms with all the hemp eaten away and the core filled with teredo, and one hemp-covered cable, laid between Crete and Egypt in 1859, had all its hemp eaten off by teredo in a short time.

Similar accounts of teredo attacking cables are given by Mance, 1875 (teredo riddling gutta-percha cable in Karachi Harbour in ten months); Bontemps 1877 ("teredo entering the hemp covering and penetrating to the gutta-percha wherever the interstices of the wires of the exterior envelope afforded them an opening"); Jungersen, 1906 (submarine telegraph cables from the Pacific Ocean, the North Sea (between Denmark and England), and the coast of Finland being damaged by teredo; caoutchouc (rubber) appearing more resistant than gutta-percha); and Jona, 1913 (*Teredo norvegica* infesting the cable from Naples to Palermo even at depths of 3,500 m). There is also a passing reference to *Teredo navalis* attacking lead, by Snoke and Richards (1956), who cite as their authority the following paper not available to this author: "Notes on everyday cable problems, failures due to animals, birds and insects" in *Distribution Elec.* 8, 1896 (1935).

Hemp is perhaps a suitable substitute for timber for a cellulose-eating animal but the records of gutta-percha infestation would seem to indicate that a cellulose burrowing medium is not an absolute requirement, either for food or for protection; and the behaviour of the larvae is by no means discriminatory. "The survival and metamorphosis of the animal is exceedingly infrequent in any material other than wood. Yet the larvae frequently try to colonise materials entirely unsuitable to the sustaining of the adult teredo. They have been reputed attempting to burrow into Manila cordage, cork, and various plastic material; they have even been held responsible for the microimpressions that are often observed in the lead sheathing of submarine cables. It is possible that the receptors of the larvae of the teredo are more sensitive to the character of the microfauna adhering to the surface of the object than they are to the nature of the surface itself" (Lane, 1961).

Necessity of Wood in Teredo Diet

Teredo normally lives and bores in wood and passes wood fibres through its digestive system. Does it need wood in its diet?

Lane (1955) discussed the question of "whether wood alone constitutes

an adequate diet, or whether other, supplementary sources are also required. Pointing out that teredo ingests wood, and has been shown to possess an active enzyme system which permits the utilisation of wood in carbohydrate metabolism, and that chromatographic analysis of hydrolysates of teredo and wood indicated some amino acids to be common to both, he concluded: "It appears that teredo uses wood as a preliminary source of carbohydrates for energy and for immediate metabolism. Wood also contributes certain of the amino acids required by the borers. However, to complete the amino acid pattern typical of the animal, another protein source must be available. It now appears that the accessory source of protein most readily available to teredo is the nannoplankton of the coastal waters in which it lives."

From these statements, based on earlier work by Lasker and Lane (1953), it might be inferred that wood is a necessary item of diet. However, there seems to this author to have been a subtle but perhaps unintentional change of emphasis between the two papers on the necessity of wood in the diet.

Lasker and Lane commenced their paper thus: "The behaviour and morphology of the Teredinidae dictate that the organisms obtain their nourishment either from the wood in which they live as adults, from particulate matter suspended in the water of the respiratory stream, or from a combination of these two sources." After pointing out that wood excavated by the largest teredo they encountered would supply the total (Kjeldahl) nitrogen actually found in the animal (0·0016 g) and leave an excess of only 0·008 g to supply that which must have been lost by digestive inefficiency, excretion, and metabolism during the life of the animal which may extend from ten to fifteen weeks, they concluded, "It is felt that this excess is inadequate quantitatively. The qualitative inadequacy of wood as a source of nitrogen for *Teredo* has been discussed . . . On the contrary, a safe excess of nitrogen in the form of amino acids shown to be deficient in wood, is available in nannoplanktonic proteins. It is suggested, therefore, that *Teredo* satisfies its nitrogen requirements by making use both of wood and of suspended planktonic organisms."

Historically, for a long time there were considerable doubts as to whether teredo used wood at all for food. Dore and Miller (1923) made the first satisfactory experimental approach to the subject by chemically analysing and comparing samples of wood frass ejected by *Teredo* and samples of the original wood from which the frass was derived and found a loss of 80% of the cellulose content and 15% to 56% of the hemicelluloses. They concluded that the disappearance of the carbohydrates was probably due to digestion as food, and subsequent work has supported their conclusions (see Kofoid and Miller, 1927; Greenfield, 1959). Dore and Miller concluded: "The digestible carbohydrates in the wood may play an important role in the economy of *Teredo* in supplying energy for its boring activities, supplementing the plankton diet upon which it mainly depends for growth and repair."

This still seems to be the more satisfactory statement for these reasons – given, in part, in Dore and Miller:

(1) Like other lamellibranchs, teredo is very well equipped to deal with

planktonic food. Its planktonic food gathering system is linked with respiration and planktonic feeding is possible continuously, so long as the animal is siphoning water. "Along the entire length (of the body) there stretches a cavity divided down the centre by a delicate lattice-work of tissues. Water enters the body of the animal through one of the siphons and passes into one of these divisions, it is then filtered through the lattice-work, leaving behind it any food particles which are carried to the mouth, passing into the second chamber from which it is expelled by way of the other siphon. In this way, the animal obtains both oxygen for respiration and a certain amount of food" (Russell and Yonge, 1949).

Then, too, Kofoid and Miller (1927) found as much as 11% by volume of the contents of the intestine in *Teredo navalis* may consist of "diatoms and other forms which leave skeletal remains . . . (Their) presence . . . would indicate the ingestion of a proportional number of flagellates and ciliates and other forms which after digestion would not leave any recognisable remains". Under normal conditions, this planktonic food supply is unlimited. It is also easily obtained.

(2) Teredo burrows are generally little larger than the body of the inhabiting animal. Dore and Miller (1923) estimated that approximately 50% of the original wood substance passed through the digestive tract unaltered. This does not leave a very abundant food supply for the entire life-cycle of a fast-growing animal. Wood is somewhat harder to come by than plankton and burrowing for food demands a considerable expenditure of energy which would further reduce the amount of nutriment available for growth, as distinct from burrowing.

(3) When teredo find their path completely blocked by other burrows or by the confines of the wood in which they are boring, they seal off the inner end of the burrow with a calcareous cap but leave the siphon end open. Indisputable evidence has yet to be produced that the presence of the cap causes death despite Lane's statement that it "effectively terminates growth and the continued life of the animal", a statement which may be based on the work of Johnson, McNeill and Iredale (1936). These authors "amplify" a statement about Northern Hemisphere teredo that "shipworms . . . eventually stop burrowing but continue to live and feast and reproduce, no one really knows for how long a period" by conclusions that Australian teredo suffer a marked mortality "soon after a test sample reaches a stage of destruction accepted as 100%, when no further timber fibre remains to be absorbed. . . . A further fact gleaned was that the life span of (teredo) is governed by the period during which it is able to indulge in active boring operations". However, as they went on to point out themselves, they had no evidence of the life span of their animals locally under unrestricted boring conditions, their own work having been confined to standardised test samples of limited size which were quickly riddled. Further, their own data would seem to stand another interpretation with regard to ability to bore actively governing life span. For example, their December "Manly" Sample, immersed 20 December 1932, was considered at the 100% stage of destruction on 22 March 1933, but on 28 August 1933, they observed that "Live animals noted in a large end section cut were mostly *Teredo austini*, many of which were in a

sexually ripe condition". On 22 September "examination showed 20% live animals . . . mostly *Bankia*" and on 23 January 1934, they concluded that, "The initial infestation by (teredo) apparently occurred within a few days of immersion of the sample in December 1932. In the subsequent three months the 100% stage of destruction was reached. The passage of another nine months was required before the animals had practically died out. The span of life, from initial infestation to virtually complete mortality, covered practically the full year's cycle of the sample."

Capping off the burrow seems to be a highly complicated method of committing suicide. Might it not be a behaviour pattern which ensures complete protection while the teredo continues life feeding entirely on plankton?

Possibility of Existence on Plankton Alone

Can teredo exist on plankton alone? The only argument against this in the literature is one which might be inferred from Lane's summary of Lasker and Lane's amino acid work. They showed that wood could be a source of certain amino acids they found missing from plankton. If wood were the only possible source of these amino acids, ignoring the possibilities of synthesis by the animal itself, it would be a fair conclusion that wood was essential to the diet. However, it can be shown that wood is not the only possible source.

Of the eight amino acids which Lasker and Lane found in teredo hydrolysates, valine, tyrosine, and proline were found in hydrolysates of plankton but not of wood. Leucine was found in both plankton and wood. Phenylalanine was found in neither but Lane suggests the possibility of interconversion between phenylalanine and tyrosine must not be overlooked. This leaves methionine, alanine, and arginine apparently to be supplied by the wood in which they were, admittedly, found.

Erdman, Marlett and Hanson (1956) have positively identified alanine and tentatively arginine in marine mud. Vallentyne (1957) lists α-alanine as being found free in aquatic sediments and α-alanine and arginine in hydrolysates of aquatic sediments. Customarily, the wood around teredo burrows is covered with sediment and the animals can hardly avoid taking in mud during normal siphoning activity. Erdman *et al.* also found valine, leucines, proline, tyrosine and phenylalanine free in their mud samples.

The remaining amino acid, methionine, is considered an essential amino acid in the metabolism of most, if not all animals, and must either be derived from the animal's diet, or perhaps from the biosynthetic activity of the gut microflora. It would be surprising if it were entirely absent from plankton ingested by teredo and its reported absence from Lasker and Lane's nannoplankton list is therefore questionable.

Thus, while Lasker and Lane's work very nicely reinforces the suggestion that teredo uses wood for energy and metabolism, it does not establish beyond any doubt the necessity for wood in the teredo diet.

CONCLUSIONS

This record of teredo, whilst by no means ruling out other possibilities, suggests that breeding populations of the common New Zealand shallow water teredo, *Bankia australis*, exist 13 miles offshore at a depth of 70 fathoms and are equally, if not more, destructive than at surface level. The fact that the growth rate compares unfavourably with shallow water specimens which, in Wellington Harbour, may reach 8 in. in 8 months (Ralph and Hurley, 1952) is not necessarily significant – the intensity of infestation and the thickness of the wood in the example concerned are sufficient to limit the majority of the specimens to a length of less than 2 in. Nor is there any indication that infestation took place immediately after sinking although it is suggested that most of the larvae settled more or less simultaneously. The possibility must be considered that breeding populations of *Bankia* can exist independently of wood, perhaps burrowing in sandstone or mudstone, and feeding mainly or entirely on nannoplankton and other particulate matter.

ACKNOWLEDGMENTS

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A NEW ZEALAND PHYTOCHEMICAL SURVEY— PART 4

THE MOSSES

By R. C. Cambie, Department of Chemistry, University of Auckland; B. F. Cain and S. La Roche, British Empire Cancer Campaign Society Laboratory, Cornwall Hospital, Auckland.

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Summary

Two hundred and fifty-one mosses of the New Zealand flora have been examined for the presence of alkaloids, leucoanthocyanins, saponins, and triterpenes or steroids. All have given negative tests.

Introduction

In a continuation of a survey of the New Zealand flora for the presence of alkaloids, leucoanthocyanins, saponins, and triterpenes or steroids, mosses found growing in New Zealand have been examined by methods outlined in the previous papers (Cain, Scannell and Cambie, 1961; Cambie, Cain and La Roche, 1961a, 1961b). Of 251 species or varieties investigated all gave negative tests for each type of compound. A few mosses gave weak froth tests stable for a few minutes only and although they may contain small amounts of saponins the tests are recorded as negative.

The species examined are listed in Table 1 according to the conspectus of classification given by Sainsbury (1955) with species in each genus arranged in alphabetical order. The samples tested formed a duplicate set of named material lodged in the herbarium of the Auckland Institute and Museum and belonged to the George Irwin moss collection. The majority of samples had been collected by G. O. K. Sainsbury and the numbers used in Table 1 refer to duplicate material in the Sainsbury collection which is held in the herbarium of the Dominion Museum, Wellington. In some cases tests on the herbarium samples were checked against those on living mosses collected in the Auckland and Central North Island areas. Identical results were obtained in all cases and are therefore not listed.

Table 1

Class MUSCI

Subclass 1 SPHAGNALES

Family 1 Sphagnaceae

Sphagnum australe Mitt. (12486), *S. cristatum* Hampe. (485), *S. falcatulum* Besch. (12616).

Subclass 2 ANDREAEALES

Family 2 ANDREAEACEAE

Andreaea acuminata Mitt. (6109), *A, acutifolia* H.f. and W. (10789),
A. australis F. Muell. (15580), *A. nitida* H.f. & W. (1006),
A. rupestris Hedw. (1225), *A. subulata* Harv. (12704).

Subclass 3 BRYALES

Clan NEMATODONTEAE

Order 1 TETRAPHIDALES

Family 3 GEORGIACEAE

Tetraphis browniana (Dicks.) Grev.

Order 3 POLYTRICHALES
Suborder POLYTRICHINEAE

Family 5 POLYTRICHACEAE

Polytrichum alpinum Hedw., *P. commune* Hedw. (11452), *P. juniperinum* Hedw. (4315).
Polytrichadelphus magellanicus (Hedw.) Mitt. (4298).
Pogonatum subulatum (Menz.) Brid. (11375).
Psilopilum australe (H.f. & W.) Jaeg., *P. crispulum* (H.f. & W.) Jaeg. (4361).
Oligotrichum tenuirostre (Hook.) Jaeg.
Atrichum ligulatum Mitt. (11812).
Dendroligotrichum dendroides (Hedw.) Broth.

Clan ARTHRODONTEAE

Subclan HAPLOLEPIDEAE

Order 4 FISSIDENTALES

Family 7 FISSIDENTACEAE

Fissidens asplenioides Hedw. (13213), *F. hylogenes* Dix., *F. pungens* C.M. & Hampe, *F. leptocladus* C.M. e Rodway (579), *F. rigidulus* C.M. (3170).

Order 5 GRIMMIALES

Family 8 GRIMMIACEAE

Grimmia apocarpa Hedw. (3241), *G. argentea R. Br. ter.* (910),
G. inaequalis Dix. & Sainsb. (823), *G. pulvinata* (Hedw.) Sm.
Rhacomitrium crispulum (H.f. & W.) H.f. & W. (4463), *R. lanuginosum* (Hedw.) Brid. var. *pruinosum* H.f. & W., *R. ptychophyllum* Mitt. (4492), *R. striatipilum* Card.
Coscindon australis Dix. & Sainsb. (827).

Order 6 DICRANALES

Family 9 ARCHIDIACEAE

Archidium elatum Dix. & Sainsb. (961)

Family 10 DITRICHACEAE

Pleuridium nervosum (Hook.) (4272).
Ditrichum flexifolium (Hook.) Hampe (2893), *D. punctulatum* Mitt.,
Distichium capillaceum (Hedw.) (2804).
Pseudodistichium buchanani (R. Br. ter.) Dix.
Saelania glaucescens (Hedw.) Broth.
Ceratodon purpureus (Hedw.) Brid. (2176).

Family 11 SELIGERIACEAE

Seligeria cardotii R. Br. ter.,
Blindia tenuifolia (H.f. & W.) Mitt.

Family 12 DICRANACEAE

Trematodon suberectus Mitt. (7596).
Campylopodium euphorocladium (C.M.) Besch. (7494).
Leucobryum candidum (Brid.) H.f. & W. (5440.).
Dicranella cardotii (R. Br. ter.) Dix., D. *jamesonii* (Mitt.) Broth. (2434).
Campylopus arboricola Card. & Dix. (1999), *C. clavatus* (R. Br.) H.f. & W. (4886), *C. holomitrium* (C.M.) Jaeg., *C. introflexus* (Hedw.) Mitt. (7683), *C. torquatus* Mitt.
Holomitrium perichaetiale (Hook.) Brid. (3322).
Dicranoweisia antarctica (C.M.) Par. (8949), *D. spenceri* Dix. & Sainsb. (2743), *D. trichopodum* Mitt. (6821).
Dicnemoloma sieberianum (Hornsch.) Ren. (8923),
Dicranoloma cylindropyxis (C.M.) Dix., *D. dicarpum* (Hornsch.) Par. *D. fasciatum* (Hedw.) Par. *D. menziesii* (H.f. & W.) Par.
Dicranoloma obesifolium (R. Br. ter.) Broth., *D. platycaulon* (C.M.) Dix.

Family 13 DICNEMONACEAE

Dicnemon calycinum (Hook.) Schwaegr. (15401),
Mesotus celatus Mitt. (3977).
Eucamptodon inflatus (H.f. & W.) Mitt. (5265).

Order 7 POTTIALES

Family 15 POTTIACEAE

Subfamily PLEUROWEISIOIDEAE

Anoectangium bellii Broth.

Subfamily TRICHOSTOMOIDEAE

Gymnostomum calcareum Bry. germ. (15336), *G. calcareum* Bry. germ. var. *longifolium* Dix.
Hyophila novae-seelandiae Dix. & Sainsb. (3374).
Eucladium irroratum (Mitt.).
Tridontium tasmanicum Hook. f. (13350).
Triquetrella curvifolia Dix. & Sainsb. (1097), *T. Papillata* (H.f. & W.) Broth. (5421).
Leptodontium interruptum (Mitt.) Broth. (10475).
Erythrobarbula binnsii (R. Br. ter.) Sainsb. (16291).
Tortella calycina (Schwaegr.) Dix. (12888), *T. knightii* (Mitt.) Broth., *T. rubripes* (Mitt.) Broth. (12954).
Barbula australasiae (Hook. & Grev.) Brid. (6207), *B. pseudopilifera* C.M. & Hpe. (12997).

Subfamily POTTIOIDEAE

Calyptopogon mnioides (Schwaegr.) Broth. (7121).
Pottia stevensii R. Br. ter. (15945), *P. zealandiae* (R. Br. ter.) Par.
Desmatodon convolutus (Brid.) Grout.
Tortula abruptinervis Dix. (4929), *T. bealeyensis* R. Br. ter., *T. laevipila* (Brid.) Schwaegr., *T. muralis* Hedw. (17363), *T. phaea* (H.f. & W.) Dix (4984), *T. papillosa* Wils., *T. princeps* De Not. (5007), *T. rubra* Mitt., *T. serrulata* Hook. & Grev. (5016).

Subclan HETEROLEPIDAE

Order 8 ENCALYPTALES

Family 16 ENCALYPTACEAE

Encalypta vulgaris Hedw. (9379).

Subclan DIPLOLEPIDEAE

Order 9 ORTHOTRICHALES

Family 17 ERPODIACEAE

Aulacopilum glaucum Wils. (993).

Family 18 PTYCHOMITRIACEAE

Ptychomitrium australe (Hampe) Jaeg. (4396).

Family 19 ORTHOTRICHACEAE

Amphidium cyathicarpum (Mont.) Broth.
Zygodon hookeri Hampe. (538), *Z. intermedius* B. & S.,
Z. menziesii (Schwaegr.) W. Arn.
Orthotrichum austro-cupulatum Dix. & Sainsb. (4080), *O. calvum* H.f. & W., *O. graphiomitrium* C.M. & Beck. (4115), *O. hor-*

tense Bosw., *O. pulvinatum* R. Br. ter. (7738), *O. tasmanicum* H.f. & W.

Muelleriella crassifolia (H.f. & W.) Dus.

Ulota laticiliata Malta (13419), *U. membranata* Malta, *U. viridis* Vent.

Bryodixonia perichaetialis Sainsb. (No. 6005).

Macromitrium erosulum Mitt. (3787), *M. eucalyptorum* Hampe & C.M. (3813), *M. gracile* (Hook.) Schwaegr. (10734), *M. gracile* (Hook.) *Schwaegr.* var. *retusum* (H.f. & W.) Sainsb., *M. grossirete* C.M., *M. ligulare* Mitt. (2927), *M. longirostre* (Hook.) Schwaegr., *M. longirostre* (Hook.) Schwaegr. var. *caducipilum* Martin & Sainsb., *M. longipes* (Hook.) Schwaegr. *M. orthophyllum* Mitt., *M. prorepens* (Hook.) Schwaegr., *M. weymouthii* Broth.

Schlotheimis brownii Brid. (4644), *S. campbelliana* C.M.

Order 10 FUNARIALES

Family 21 FUNARIACEAE

Funaria hygrometrica Hedw. (8035).

Physcomitrium conicum Mitt. (11335).

Family 22 SPLACHNACEAE

Tayloria octoblepharis (Hook.) Mitt. (4769).

Order 11 EUBRYALES ACROCARPI

Suborder BRYINEAE

Family 23 BRYACEAE

Mielichhoferia eckloni Hornsch. (14171)

Orthodontium lineare Schwaegr. (11045).

Pohlia cruda (Hedw.) Lindb. (5096), *P. elatior* (Dix. & Sainsb.) Sainsb.

P. nutans (Hedw.) Lind., *P. tenuifolia* (H.f. & W.) Broth.

Brachymenium preissianum Hampe (6319).

Plagiobryum novae seelandiae Broth.

Bryum appressifolium Broth. (818), *B. blandum* H.f. & W. (15594),

B. campylothecium Tayl. (1595), *B. crassum* H.f. & W., *Bryum laevigatum* H.f. & W., *B. truncorum* Brid. (13190).

Leptostomum macrocarpum (Hedw.) R. Br. (3695).

Family 24 MNIACEAE

Mnium longirostrum Brid.

Suborder RHIZOGONIINEAE

Family 25 MEESIACEAE

Meesia muelleri C.M. & Hampe.

Family 26 AULACOMNIACEAE

Leptotheca gaudichaudii Schwaegr. (7260).
Aulacomnium palustre (Hedw.) Schewaegr. (15574).

Family 29 RHIZOGONIACEAE

Hymenodon piliferus H.f. & W.
Cryptopodium bartramioides (Hook.) Brid.
Rhizogonium bifarium (Hook.) Schimp. (4550), *R. distichum* (Sw.) Brid., *R. novae-hollandiae* Brid. (4593).
Goniobryum subbasilare Lindb.

Suborder BARTRAMINEAE

Family 30 BARTRAMIACEAE

Bartramia halleriana Hedw., *B. papillata* H.f. & W. (1318).
Conostomum australe Sw. (7977).
Breutelia affinis (Hook.) Mitt. *B. pendula* (Hook.) Mitt. (6428).
Philonotis australis (Mitt.) Jaeg. (4222), *P. scabrifolia* (H.f. & W) Broth., *P. tenuis* (Tayl.) Jaeg.

EUBRYALES PLEUROCARPI

Suborder HYPNODENDRINEAE

Family 31 HYPNODENDRACEAE

Sciadocladus kerrii (Mitt.) Jaeg. e Broth. (7760), *S. menziesii* (Hook.) Lindb.
Hypnodendron arcuatum (Hedw.) Mitt. (15442), *H. marginatum* (H.f. & W.) Jaeg.
Mniodendron comosum (La Bill.) Lindb. e Broth.

Order 12 ISOBRYALES
Suborder RHACOPILINEAE

Family 32 RHACOPILACEAE

Rhacopilum robustum H.f. & W. (17368), *R. strumiferum* C.M.

Suborder LEUCODONTINEAE

Family 34 CRYPHAEACEAE

Cryphaea tasmanica Mitt. (2291), *C. tenella* (Schwaegr.) Hornsch.

Family 35 HEDWIGIACEAE

Hedwigia ciliata (Hedw.) P. Beauv. (8617).
Rhacocarpus humboldtii (Hook.) Lindb. (329).

Family 36 PTYCHOMNIACEAE

Dichelodontium nitidum (H.f. & W.) Broth.
Tetraphidopsis pusilla (H.f. & W.) Dix. (6768).
Cladomnion ericoides (Hook.) H.f. & W.
Glyphothecium sciuroides (Hook.) Hampe (9789).
Hampeella alaris (Dix. & Sainsb.) Sainsb. (719).
Ptychomnion aciculare (Brid.) Mitt. (11708).

Family 37 LEPYRODONTACEAE

Lepyrodon australis (Hampe), e Broth.

Family 38 CYRTOPODACEAE

Cyrtopus setosus (Hedw.) Hook. (8245).

Family 39 PTEROBRYACEAE

Trachyloma planifolium (Hedw.) Brid. (13182).

Family 40 METEORIACEAE

Weymouthia cochlearifolia (Schwaegr.) Dix. (5152), *W. mollis* (Hedw.) Broth. (374).
Papillaria amblyacis (C.M.) Jaeg., *P. crocea* (Hampe) Jaeg. (11154),
P. flavo-limbata (C.M. & Hampe) Jaeg., *P. nitens* (H.f. & W.) Sainsb. (11238).

Suborder NECKERINEAE

Family 41 PHYLLOGONIACEAE

Orthorrhynchium elegans (H.f. & W.) Reichdt.

Family 42 NECKERACEAE

Leptodon smithii (Hedw.) Mohr.
Neckera laevigata H.f. & W.), *N. pennata* Hedw. (11006).
Homalia falcifolia (H.f. & W.) H.f. & W. (19000).
Thamnium pandum (H.f. & W.) Jaeg. (8007).

Family 43 ECHINODIACEAE

Echinodium hispidum (H.f. & W.) Jaeg. (2985).

Family 44 LEMBOPHYLLACEAE

Camptochaete angustata (Mitt.) Jaeg. (1833), *C. gracilis* (H.f. & W.) Par. (1874).
Lembophyllum clandestinum (H.f. & W.) Lindb. (3601).

Order 13 HOOKERIALES
Suborder HOOKERIINEAE

Family 46 HOOKERIACEAE

Sauloma tenella (H.f. & W.) Mitt. (15889).
Bellia nervosa (H.f. & W.) Broth. (1355).
Eriopus cristatus (Hedw.) Jaeg. (3042), *E. apiculatus* (H.f. & W.) Mitt.
Distichophyllum microcarpum (Hedw.) Mitt., *D. pulchellum* (H.f. & W.) Mitt. (2830).
Pterygophyllum dentatum (H.f. & W.) Mitt. (245), *P. distichophylloides* Broth. & Dix., *P. quadrifarium* (Hook.) Brid.

Family 47 HYPOPTERYGIACEAE

Catharomnium ciliatum (Hedw.) H.f. & W.
Lopidium concinnum H.f. & W., (7171).
Hypopterygium filiculaeforme (Hedw.) Brid., *H. novae-seelandiae* C.M. (3538).

Order 14 HPYNOBRYALES
Suborder LESKEINEAE

Family 48 THUIDIACEAE

Thuidium furfurosum (H.f. & W.) Jaeg., *T. furfurosum* (H.f. & W.) Jaeg. var. *sparsum* (H.f. & W.) Sainsb., *T. laeviusculum* (Mitt.) Jaeg. (12806).
Haplohymenium huttonii (Mitt.) Broth.

Family 49 LESKEACEAE

Pseudoleskea imbricata (H.f. & W.) Broth. (4348).

Family 50 AMBLYSTEGIACEAE

Amblystegium serpens (Hedw.) Bry. eur. (1207).
Drepanocladus aduncus (Hedw.) Warnst. (8931), *D. fluitans* (Hedw.) Warnst.
D. fontinaliopsis (C.M.) Dix. (2960), *D. uncinatus* (Hedw.) Warnst.
Campylium polygamum (Bry. eur.) Bryhn.
Cratoneuron filicinum (Hedw.) Roth.
Cratoneuropsis relaxa (Hook. f. & W.) Fleisch. e Broth.
Acrocladium auriculatum (Mont.) Mitt. (6048), *A. cuspidatum* Lindb. (16215),
A sarmentosum (Wahl.) Richards & Wallace (8973).

Family 51 BRACHYTHECIACEAE

Brachythecium albicans Hedw. (761), *B. paradoxum* (Hook. f. & W.) Jaeg.

B. plumosum (Sw.) Bry. eur.,
Rhynchostegium laxatum (Mitt.) Par., *R. tenuifolium* (Hedw.) Jaeg. (4626).
Eriodon cylindritheca (Dix.) Dix. & Sainsb. (3028).
Eurhynchium asperipes (Mitt.) Dix. (13270).
Rhynchostegiella muriculata (H.f. & W.) Broth.

Suborder HYPNINEAE

Family 52 FABRONIACEAE

Fabronia australis Hook. (3097)

Family 53 ENTODONTACEAE

Entodon truncorum Mitt. (No. 3019)

Family 54 PLAGIOTHECIACEAE

Catagonium politum (H.f. & W.) Dus. (7915).
Plagiothecium denticulatum (Hedw.) Bry. eur. (11825).
Isopterygium albescens (Schwaegr.) Jaeg., *I. limatum* (H.f. & W.) Broth. (10397), *I. pulchellum* (Dicks.) Jaeg.

Family 55 SEMATOPHYLLACEAE

Acanthocladium extenuatum (Brid.) Mitt.
Sematophyllum amoenum (4677), *S. homomallum* (Hampe) Broth.
S. tenuirostre (Hook.) Dix. (12475).

Family 56 HYPNACEAE

Hypnum cupressiforme Hedw., *Hypnum cupressiforme* Hedw. var. *filiforme* Brid.
Ctendium pubescens (H.f. & W.) Broth. (2332).

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BIOLOGICAL AND CHEMICAL CHANGES FOLLOWING SCRUB BURNING ON A NEW ZEALAND HILL SOIL

4. MICROBIOLOGICAL CHANGES

By J. D. STOUT, Soil Bureau, Department of Scientific and Industrial Research, Wellington.

(Received for publication, 25 May 1961)

Summary

The bacterial population and microfauna of samples of litter and topsoil from an area on Taita Experimental Station were examined over a period of five years.

An account is given of the fauna prior to burning, following the burn, and in the newly established grassland soil. The changes in the fauna are related to the changes in the physical and chemical character of the habitat and the differential effect on the different animal groups.

It is concluded that these physical and chemical changes are of greater importance than the change in the organic cycle in determining the composition of the fauna.

INTRODUCTION

A preliminary report (Miller, Stout and Lee, 1955) described biological and chemical changes that accompanied the clearing, burning, and grassing of an area of gorse (*Ulex europaeus*) and manuka (*Leptospermum scoparium*) on the Taita Experimental Station of the Soil Bureau, 12 miles north of Wellington, North Island. This preliminary report covered a period of ten months from April 1954, to March 1955, and particular attention was directed to the immediate effects of the fire and the classical pattern of partial sterilisation which followed.

After five years the period of disequilibrium following the fire has given place to a new stability with the establishment of grazed pasture and consolidation of the loose litter into the soil humus. It is now possible to compare the fauna persisting in the new grassland soil with the forest fauna which was present prior to the burn when the soil was covered with gorse and manuka, and to consider the ecological differences between a forest and a grassland fauna and the effect of the different physical and chemical changes in the environment on the different groups of organisms of which the fauna consists.

The failure of many of the original forest animals to persist even when large quantities of litter remained indicates that food is not a primary critical factor. What was destroyed by the fire was not simply a food cycle of slowly decaying litter but a physical structure with properties of moisture and aeration that, unlike the residual litter, did not survive the burn. The animals most sensitive to desiccation and poor aeration, and those whose life history is prolonged, died out. Only those survived that

are tolerant of the more intensive cycle of organic degradation taking place in the grassed topsoil and capable of completing their life cycles in the new aquatic environment now severely restricted both in time and space.

In this paper, therefore, the composition of the original forest fauna and also the composition of the present grassland fauna are considered in relation to their physical and chemical factors in determining these faunal differences.

MATERIALS AND METHODS

In the preliminary report (Miller *et al.*, 1955), sub-samples, from the composite samples on which chemical analyses were carried out, were used for microbiological analyses. Samples from two heavily burned sites were also examined. However, after ten months the heavily burned sites were overgrown with pasture and the samples from them were microbiologically indistinguishable from the composite samples. Subsequent observations were therefore confined to sub-samples of the composite samples used for chemical analyses. In this way the closest correlation between the chemical and microbiological data has been preserved.

Two sets of plates, each in duplicate, for bacterial counts were poured from serial dilutions of 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6}, one with glucose (10g/l) – Bacto-tryptone (5g/l) – Difco yeast extract (4g/l) – agar (15g/l) and a second with Difco Nutrient Agar. They were counted after two days' incubation at 25°C. On occasions glucose broth tubes were also inoculated from the serial dilutions.

For the protozoa and other microfauna plain agar plates (2% agar) were poured and inoculated with 10 g of soil and 20 ml of sterile distilled water added. Cultures were prepared in duplicate and examined microscopically for several months.

These samples completed five years of observation, from April 1954, to May 1959.

RESULTS

The changes in the bacterial population and the incidence of protozoan species in the different samples are shown in Fig. 1. Table 1 lists the rhizopod fauna and summarises its distribution in the samples, and similarly Tables 2 and 3 give the same information for the ciliates and non-protozoan fauna.

A. (1) The Bacterial Flora Prior to the Burn

No detailed study was made of the bacterial flora but it seems safe to assume that the litter and soil flora prior to the burn was essentially similar to that of other samples of litter and topsoil under manuka (*Leptospermum scoparium*) taken from an adjacent area. This flora is recorded in Stout (1961). The upper litter had a strong component of flavobacteria and *Chromobacterium* was also present. Aerogenic fermenters (*Aerobacter cloacae*) were common, especially in the lower litter. Aerobic spore-forming bacteria, particularly *B. cereus* and *B. mycoides*, were present in the lower litter and were also conspicuous in the topsoil.

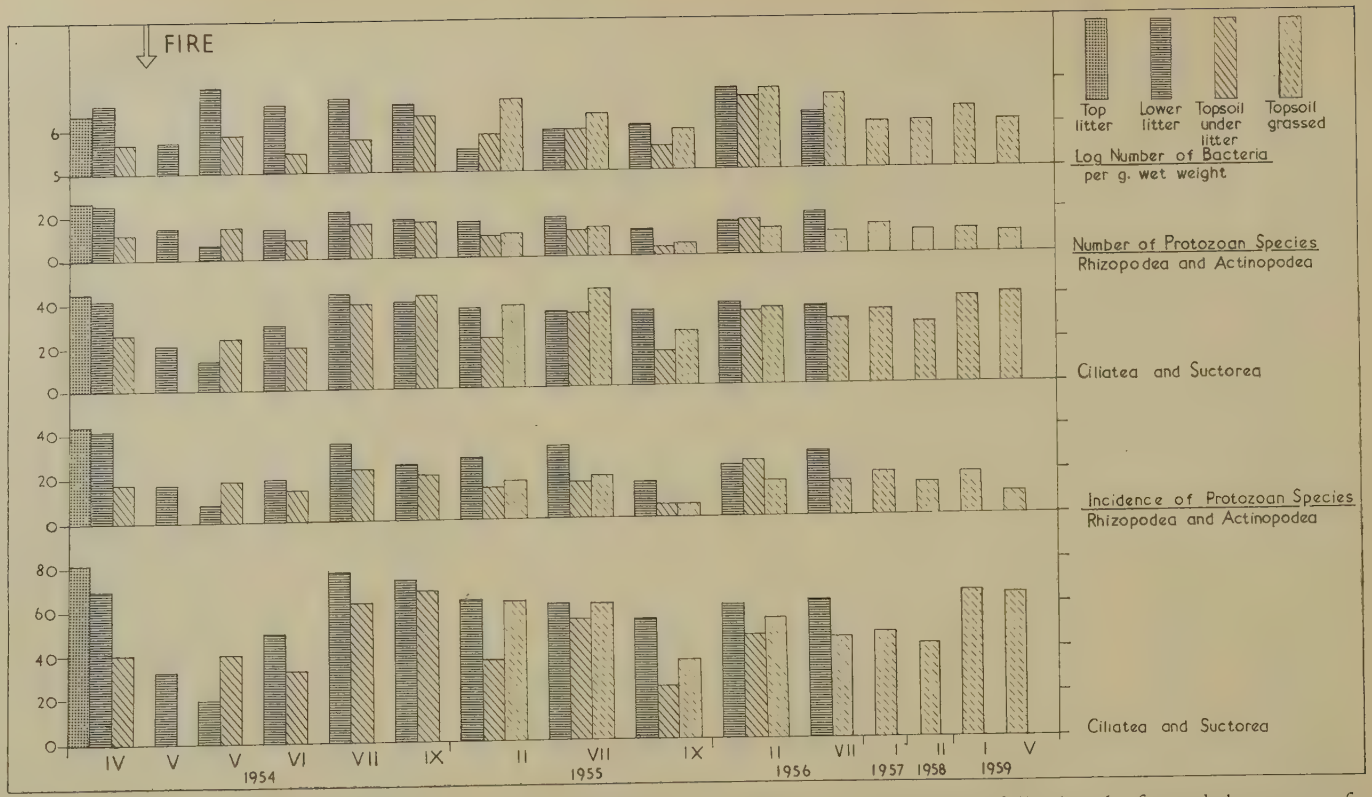
FIRE
Top litter
Lower litter
Topsoil under litter
Topsoil grassed
Log Number of Bacteria per g. wet weight
Number of Protozoan Species Rhizopodea and Actinopodea
Ciliatea and Suctorea
Incidence of Protozoan Species Rhizopodea and Actinopodea
Ciliatea and Suctorea
IV V V VI VII IX II VII IX II VII I II I V
1954 1955 1956 1957 1958 1959

FIG. 1—Summary of changes in the lightly burnt area. This shows the depression of the population following the fire and the recovery first of the bacterial population and then of the Protozoa (cf. Miller *et al.*, 1955). It shows also the relative population stability of the new grassed topsoil.

TABLE 1—Total Incidence of the Rhizopod Fauna in Samples from the Lightly Burnt and Heavily Burnt Sites Over the Five-year Period.

(The figures in parentheses for the F layer are those for the two samples collected in the first month after the burn when the fauna was most severely reduced. They are not included in the F total.)

Sites	Lightly Burnt					Heavily Burnt	
Soil Horizon	P	L	F	A_1	A_1*	A_1(H)	B(H)
RHIZOPODEA							
Nuclearia simplex	0	1	6	6	0	1	2
Biomyxa vagans	0	2	8	7	2	2	0
Mycetozoa	0	0	5	0	1	0	0
Pelomyxa sp.	0	0	1	0	0	0	0
Metachaos sp.	0	0	1	0	0	0	0
Trichamoeba sp.	1	1	15 (2)	13	13	5	2
Trichamoeba sp.	0	2	11 (1)	7	0	2	0
Trichamoeba guttula	0	0	10	6	8	0	0
Thecamoeba striata	0	2	0	0	0	0	0
Thecamoeba verrucosa	0	2	10 (1)	5	3	0	0
Mayorella vespertilio	1	2	16 (2)	14	14	2	0
Hyalodiscus sp.	0	1	8	5	4	1	0
Lecythium sp.	0	1	1	0	0	0	0
Arcella sp.	0	2	15 (2)	3	5	0	0
Centropyxis aculeata	0	2	3	0	0	0	0
Centropyxis laevigata	0	0	3	3	0	0	0
Difflugia constricta	0	2	10 (2)	8	7	0	0
Difflugia globulus	0	0	5	1	1	0	0
Difflugia pyriformis	0	1	2 (2)	3	0	0	0
Difflugia lucida	0	2	8	7	1	0	0
Difflugia arcula	0	1	2 (1)	2	5	0	0
Pseudochlamys patella	0	1	13	0	9	2	0
Nebela vas	0	2	2	0	0	0	0
Heleopora sp.	0	0	4 (1)	1	0	0	0
Corythion dubium	0	1	3 (1)	2	1	0	0
Euglypha cristata	0	2	3	1	0	0	0
Euglypha ciliata	0	2	15 (1)	6	8	0	0
Euglypha rotunda	0	1	13 (1)	9	12	1	0
Euglypha compressa	0	0	0	1	0	0	0
Assulina muscorum	0	2	3	0	0	0	0
Trinema enchelys	0	2	18 (2)	12	14	2	0
Trinema lineare	0	2	14 (3)	14	14	3	1
Trinema complanatum	0	0	0	0	1	0	0
Trinema galatea	0	0	5	1	0	0	0
Sphenoderia dentata	0	2	9 (1)	5	5	1	0
ACTINOPODEA							
Actinophrys sol	0	1	8 (1)	9	3	0	0
Raphidiophrys elegans	0	2	4 (1)	2	2	0	0
Total number of cultures (M)	1	2	18 (4)	18	18	6	2
Total number of species (TS)	2	27	34 (17)	27	22	11	3
Total species – incidence (TI)	2	44	254 (25)	153	133	22	5
Av. species – incidence (TI/TS)			7·4	5·7	6·0	2	
Total – incidence Av. species/culture (TI/M)		22	13·9	8·5	7·3	3·7	

P, green clover leaves; L, upper litter; F, lower litter; A_1, ungrassed topsoil; A_1*, grassed topsoil; B, ungrassed subsoil; (H), indicates heavily burnt sites.

There is a significant difference, at the 5% level, in the total number of species recorded from F, A_1, and A_1* and a difference in the total species incidence between F and the two topsoils, A_1 and A_1*.

TABLE 2—Total Incidence of the Ciliate Fauna in Samples from the Lightly Burnt and Heavily Burnt Sites Over the Five-year Period

(The figures in parentheses for the F layer are those for the two samples collected in the first month after the burn when the fauna was most severely reduced. They are not included in the F total.)

Sites	Lightly Burnt					Heavily Burnt	
Soil Horizon	P	L	F	A_1	A_1*	A_1(H)	B(H)
CILIATEA							
Litonotus muscorum	1	0	11	2	9	0	0
Loxophyllum utriculariae	0	2	3	0	1	1	0
Byrophyllum loxophylliforme	0	2	0	0	0	0	0
Chilodonella wisconsinensis	1	0	3	5	7	0	0
Chilodonella gourandi	0	2	13 (1)	2	4	1	0
Chilodonella cucullus	0	0	4	2	1	1	0
Gastronauta membranaceus	1	1	13	4	10	0	0
Nassula tumida	0	0	2	0	6	0	0
Enchelys sp.	0	2	15 (2)	7	5	1	0
Chaenea sp.	0	0	3	3	3	0	0
Lagynophyra sp.	0	0	3	3	7	0	0
Lacrymaria sp.	0	2	3	1	6	0	0
Lacrymaria olor	0	0	0	0	0	1	0
Trachellophyllum sp.	0	0	2	2	3	0	0
Chilodontopsis muscorum	0	2	6	3	2	0	0
Spathidium amphoriforme	0	2	16 (1)	9	10	2	0
Spathidium papilliferum	0	2	5	1	0	0	0
Spathidium sp.	1	2	12 (1)	5	9	1	0
Dileptus anguillula	0	2	14	16	9	1	0
Dileptus conspicuus	0	2	3	0	0	0	0
Dileptus amphileptoides	0	2	2	1	5	0	0
Dileptus binucleatus	0	0	1	2	2	0	0
Colpoda cucullus	1	2	17 (2)	10	17	3	0
Colpoda maupasi	1	0	1	0	0	0	0
Colpoda steinii	1	2	12 (4)	10	5	3	0
Colpoda inflata	1	1	11 (4)	11	3	3	0
Bresslaua vorax	1	0	5 (1)	1	2	0	0
Mycterothrix tuamotuensis	0	1	3	0	1	0	0
Plagiopyla sp.	1	2	13	13	14	3	0
Leptopharynx sphagnetorum	1	2	18 (4)	17	18	4	0
Drepanomonas sphagni	0	2	8 (1)	3	6	1	0
Drepanomonas revoluta	1	0	0	0	1	0	0
Microthorax simulans	0	0	1	1	6	0	0
Kreyella muscicola	0	0	4	2	4	1	2
Frontonia depressa	0	0	16 (1)	12	10	1	0
Cyrtolophosis mucicola	1	2	13 (2)	13	13	2	0
Cinetochilum margaritaceum	0	2	10	10	13	2	0
Pseudoglaucoma muscorum	0	1	4	3	4	0	0
Homalogastra setosa	0	2	12	5	11	3	0
Sathrophilus muscorum	1	2	17 (1)	16	16	2	0
Tetrahymena pyriformis	0	0	5 (1)	1	2	0	0
Tetrahymena rostrata	0	2	15 (3)	10	6	1	0

TABLE 2—*continued*

Sites	Lightly Burnt					Heavily Burnt	
Soil Horizon	P	L	F	A_1	A_1*	A_1(H)	B(H)
Cyclidium muscicola	1	2	18	11	14	3	0
Cohnilembus fusiformis	0	0	11	6	2	2	0
Cohnilembus sp.	0	0	2	2	3	1	0
Byrometopus pseudochilodon	0	2	6	11	4	1	0
Blepharisma steini	0	2	4	2	14	2	0
Blepharisma hyalinum	0	2	8	3	6	0	0
Phacodinium metschnicoffi	0	2	5	2	7	0	0
Stentor multiformis	0	1	0	0	0	0	0
Halteria grandinella	0	2	16 (2)	17	14	2	0
Uroleptus musculus	0	0	2	3	4	0	0
Uroleptus sp.	0	1	14 (1)	9	5	0	0
Hemicycliostyla sp.	0	2	6 (2)	3	5	0	0
Keronopsis muscorum	1	2	15 (3)	15	15	3	0
Onychodromus sp.	0	2	16	10	8	4	0
Gonostomum affine	1	2	18 (4)	17	17	4	0
Oxytricha fallax	1	1	12 (2)	3	14	1	0
Oxytricha setigera	0	2	16 (3)	15	14	4	0
Oxytricha pellionella	0	1	10 (3)	9	10	1	0
Oxytricha sp.	0	0	2	1	5	2	0
Psilotricha sp.	0	1	4	11	5	0	0
Euplotes muscicola	0	2	17 (1)	9	12	2	0
Aspidisca sp.	0	0	4	9	5	3	0
Opercularia frondicola	0	0	1	1	0	1	0
Opercularia sp.	1	0	9	3	12	3	0
Epistylis sp.	0	0	1	0	1	1	0
Vorticella striata	0	2	18 (2)	17	18	4	0
Vorticella sp.	0	0	4	7	8	3	0
Tokophrya sp.	0	0	3 (1)	1	6	1	0
Podophyra sp.	0	0	2	0	0	0	0
Lecanophyra sp.	0	2	3	0	0	0	0
Total number of cultures (M)	1	2	18 (4)	18	18	6	2
Total number of species (TS)	19	45	68 (26)	60	63	42	1
Total species – incidence (TI)	19	81	566(53)	403	479	86	2
Av. species – incidence (TI/TS) Total – incidence			8·3	6·7	7·6	2·0	
Av. species/culture (TI/M)		40·5	31·3	22·4	26·6	14·3	

P, green clover leaves; L, upper litter; F, lower litter; A_1, ungrassed topsoil; A_1*, grassed topsoil; B, ungrassed subsoil; (H), indicates heavily burnt sites.

There is no significant difference, at the 5% level, in the number of species occurring in F, A_1, and A_1*, but there is a significant difference in the total incidence figures between each of the three.

In comparing the present list of species with previous lists (Stout, 1958; 1960) attention is drawn to the change in generic names due to homonymy. The names affected, with the homonyms in brackets, are: *Litonotus* (*Lionotus*), *Leptopharynx* (*Trichopelma*), *Sathrophilus* (*Saprophilus*) (cf. *Corliss*, 1960).

TABLE 3—Incidence of the Microfauna Other Than Protozoa

Date	Horizon	Nematoda	Rotifera	Gastrotricha	Tardigrada	Turbellaria	*Aeolosoma niveum*	*Aeolosoma kashyapi*	*Pristina taita*	Enchytraeidae	Copepoda	Collembola	Insecta larvae	Acarina
30.4.54	L	x	x	x	x	x	–	–	–	x	x	–	x	x
	F	x	x	x	x	x	x	x	x	x	x	–	–	x
	A_1	x	x	x	x	x	–	–	–	–	x	–	–	–
3.5.54	F	x	x	x	x	–	–	–	–	–	–	–	x	x
4.5.54	A_1(H)	–	–	x	–	–	–	–	–	–	–	–	–	–
	B (H)	–	–	–	–	–	–	–	–	–	–	–	–	–
21.5.54	F	x	x	–	x	–	–	–	–	–	–	–	–	x
	A_1	x	x	x	x	–	–	–	–	–	–	–	–	–
30.6.54	F	x	x	x	x	–	–	–	–	–	–	–	–	–
	A_1	x	x	–	x	–	–	–	–	–	–	–	–	–
19.7.54	F	x	x	–	x	–	x	–	–	x	x	–	–	x
	A_1	x	x	–	–	x	–	x	–	–	x	–	–	–
	A_1(H)	x	x	–	–	–	–	–	–	–	x	–	x	x
28.9.54	F	x	x	x	x	x	–	–	–	–	–	–	–	x
	A_1	x	x	–	–	–	x	x	–	x	–	x	x	–
22.2.55	F	x	x	–	x	–	–	–	–	–	–	–	–	x
	A_1	x	x	–	x	–	–	x	–	x	x	–	–	–
	A_1*	x	x	–	–	–	x	x	–	–	–	–	–	x
1.3.55	A_1(H)	x	x	x	–	–	x	–	–	–	x	–	–	–
26.7.55	F	x	x	–	x	–	x	–	–	x	–	x	–	–
	A_1	x	x	x	x	x	x	–	–	–	–	–	–	x
	A_1*	x	x	x	x	–	x	–	–	x	–	x	x	–
27.9.55	F	x	x	–	x	x	x	x	–	–	–	–	–	–
	A_1	x	x	x	–	–	x	–	–	–	–	x	–	–
	A_1*	x	x	–	x	–	–	–	–	x	–	–	–	–
21.2.56	F	x	x	–	–	–	–	–	–	–	–	–	–	–
	A_1	x	x	x	x	x	x	x	–	x	–	–	–	–
	A_1*	x	x	–	x	–	x	–	–	x	–	–	–	–
17.7.56	F	x	x	x	x	x	–	–	–	x	–	–	–	–
	A_1*	x	x	x	x	–	–	x	–	x	–	–	–	–
17.1.57	P	–	x	–	–	–	–	–	–	–	–	–	–	–
	A_1*	x	x	x	x	–	x	–	–	x	–	–	–	–
12.2.58	A_1*	x	x	–	–	x	x	–	–	x	–	–	–	–
16.1.59	A_1*	x	x	–	x	–	x	–	–	x	–	–	–	–
25.5.59	A_1*	x	x	x	x	–	–	–	–	–	–	–	–	–

x, present; –, absent.

P, green clover leaves; L, upper litter; F, lower litter;

A_1, ungrassed topsoil; A_1*, grassed topsoil; B, ungrassed subsoil.

(H) indicates samples from the heavily burnt area.

A. (2) The Fauna Prior to the Burn

The fauna prior to the burn was a forest fauna distributed in three horizons: an L, or upper litter horizon consisting of up to an inch of dry, dead twigs and leaves of gorse and manuka; an F, or lower litter horizon consisting of up to two inches of partially decomposed moist leaves and twigs of gorse and manuka; and an A_1 or topsoil horizon consisting of up to six inches of dark greyish brown heavy silt loam with the roots mainly in the top two inches.

Chemically the two litter layers were similar: moderately acid (pH 5·9 and 5·6) with over 2% nitrogen and over 100 mg% phosphate and with C/N ratios of 27 and 23. The principal distinction between the two lay in the moisture figures, 35% for the L layer and 69% for the F layer.

The topsoil was more acid (pH 5·0), low in phosphate and nitrogen and with a C/N ratio of 14. The cation-exchange capacity was 21·5 me.% and the total exchangeable bases 9·3 me.% giving a base saturation of 43%. Moisture was 35% but since this is on a weight basis and the density of the topsoil is over ten times that of the litter this figure is not directly comparable with the litter figures. It indicates a moisture content close to field capacity.

Biologically the litter layers were distinguished from the topsoil by the greater diversity of microfauna. There was little difference in the protozoan faunas of the upper and lower litter layers but the lower litter was distinguished from the upper litter by the presence of aquatic oligochaetes, two aeolosomatids and a naidid. Altogether 32 species of Sarcodina (rhizopods and actinopods) were recorded from the litter layers including a mycetozoan, eight species of amoebae and twenty species of testacea. Fifty-three ciliate species were recorded from the litter layers. These included two very rare species, *Mycterothrix tuatuomensis* and *Stentor multiformis*, previously only recorded from moss which were found in the upper litter, and two species epibiotic on copepods, namely *Opercularia frondicola* and *Lecanophrya* sp. The topsoil had only 12 species of Sarcodina, including two amoeba species and 9 testaceans, and only 27 ciliate species, generally the smaller and more common species and excluding the copepod epibionts. Nematodes, rotifers, gastrotrichs, tardigrades, turbellaria and copepods* were present both in the litter and the topsoil. Enchytraeids were present only in the litter. Insect larvae and mites were also observed in the litter samples though they are more strictly part of the mesofauna (cf. Miller *et al.*, 1955, Table 7).

B. The Fauna Following the Fire

The fauna succeeding the fire showed considerable instability associated with the physical, chemical, and pedological disequilibrium caused by the fire.

**Epactophanes richardi* and *Bryocamptus stouti* were identified from manuka litter from an adjacent area by Dr J. P. Harding of the British Museum. It seems very likely that these were the two species present in the samples from the "burn" area.

Physically the fire destroyed the dry upper litter and subjected the underlying litter and the topsoil to varying intensities of high temperature. Chemically, conversion of the litter to ash released large quantities of phosphate, potash, calcium and magnesium in a readily soluble form. The effect of this was greatly to increase available bases in the soil and raise the pH by 2 units in the remaining litter and about half a unit in the topsoil (cf. Miller and Fitzpatrick, 1959).

In the period succeeding the fire the area presented a mosaic of ecological niches reflecting the intensity of the fire at different points and the degree to which the litter had been destroyed. The remaining litter, no longer replenished, slowly disappeared from the surface of the soil remaining longer in the hollows and depressions and disappearing most rapidly from the humps. Similarly the ryegrass—clover pasture, sown immediately after the burn, steadily established itself over the area covering the bare patches left by the complete destruction of the litter and growing through the remaining litter patches. Sufficient patches of litter remained for sampling up till July 1956, and even after this period undecomposed litter was recognisable in the grassed topsoil samples forming about 1% by weight of the January 1959 samples. However, by May 1959, five years after the fire, all that could be recognised were a few short charred pieces of wood or twig. All the remaining litter had been decomposed or converted to soil humus. Bare patches free of litter which the grass had not covered remained for sampling up till February 1956, but from then onwards the grazed pasture became more and more strongly established forming with the incorporated organic matter from the litter a distinct turf.

Biologically, the immediate effect of the fire was one of partial sterilisation of the litter but there was considerable recovery reaching a climax within three months of the fire. Subsequently there was adaptation of the fauna to the new ecological niche provided by the grassed topsoil (cf. Miller *et al.*, 1955).

Pristina taita Stout (1956) did not recur after the burn and copepods though present in samples collected in July 1954, occurred only sporadically thereafter. The turbellaria, enchytraeids and aeolosomatids persisted although they occurred in fewer numbers in the cultures. Of the protozoan litter fauna the rhizopods were much more severely affected than the ciliates.

In contrast to the litter fauna which was depleted by the consequences of the fire the topsoil fauna was enriched. This was undoubtedly due to the incorporation of litter into the topsoil and the acquisition of the associated litter animals. Thus both aeolosomatids and turbellarians were recorded from topsoil samples after the fire and many species of rhizopods and ciliates not initially recorded from the topsoil were added to its fauna.

C. (1) The Bacterial Flora of the Pasture Soil

In October 1959, an estimate was made not only of the total bacterial population but also of the aerogenic fermenters (presumably *Aerobacter cloacae*) and of the aerobic spore-forming bacilli. The population of

aerogenic fermenters was about 1,000/g wet weight. The aerobic spore-forming bacteria averaged about 100,000/g wet weight or 5%–10% of the total population of aerobic heterotrophs. *Bacillus cereus*, *B. mycoides*, and *B. megaterium* were the dominant species. On this occasion a colony of *Pseudomonas fluorescens* was observed on the plates for the first time. It is possible that it may herald the establishment of a pseudomonad flora similar to that found in certain natural (Stout, 1958) and exotic (Stout, 1960) grassland soils. Streptomyces were common in the microflora of the pasture soil over the later samplings. It was also observed that diatoms grew regularly in the later protozoan cultures.

C. (2) The Fauna of the Pasture Soil

With the establishment of the grassed topsoil a new ecological equilibrium was attained. Initially the grassed topsoil included undecomposed litter but this became increasingly of less importance and it is clear that a new faunal stability, independent of the original niches has been established.

This topsoil niche is remarkable for a very high proportion of organic matter and a high base saturation, both consequences of its history. The organic carbon figure is of the order of 10% as compared with a figure of 5%–6% normal for this soil type. This high proportion of organic matter increases the exchange capacity of the soil which is about 33 me.% as compared with a normal figure of about 20 me.% but the high proportion of bases remaining from the ash results in a base saturation of 76% as against the normal 42%. This topsoil is a rich black loam interwoven with grass roots forming a marked contrast with the original forest profile.

The fauna of this niche consists predominantly of ciliate protozoa which have remained at about 23 to 33 species per culture for the last three or four years of sampling. The Sarcodina are far more poorly represented, there being few species and these represented by few individuals. While nematodes, rotifers, and tardigrades have remained, other invertebrates have slowly disappeared as the populations have failed in the new environment. Turbellarians and copepods were absent from the last two sets of samples and aeolosomatids and enchytraeids were uncommon. Compared with the original litter and topsoil faunas this new grassland fauna differs in being less diverse. Only the most versatile soil animals have established themselves in the new niche.

D. A Comparison of the Litter Fauna, Forest Topsoil Fauna, and Grassland Topsoil Fauna

(i) Quantitative

All but one of the rhizopod and actinopod species recorded were found in the forest profile and all but two were found in the litter layers. Conversely only about two-thirds of the species were recorded from the heavily burnt sites and grassed topsoil. Not only were more species present in the forest soil but in the litter the incidence of species in the cultures was much higher than in the grassland soil.

There was no significant difference in the number of ciliate species occurring in the litter, the forest topsoil and the grassland topsoil. The incidence of species, however, was highest in the litter and, in contrast to the rhizopods, was higher in the grassed topsoil than in the forest topsoil.

The preference of the rhizopods for the forest litter rather than for soil or fresh vegetation is also shown by the fauna of the green clover leaves from which only two species of amoebae were recorded although 19 species of ciliates were present. Similarly the incidence of only 11 species of rhizopods in the heavily burnt sites compared with 42 species of ciliates indicates the greater versatility of the ciliate population.

Another indication of the contrast between litter and soil as a habitat for protozoa is given by the number of common species. In litter there were 13 species of rhizopods which occurred in at least half of the cultures whereas there were only 6 such common species in each of the two topsoils. With ciliates there were 31 species occurring in at least half of the litter cultures and 25 in each of the topsoils.

(ii) QUALITATIVE

Of the rhizopods there were four species which were present before the burn but which did not occur thereafter. These were *Thecamoeba striata, Lecythium* sp., *Centropyxis aculeata* and *Nebela vas.* The great majority of species, however, survived the burn and persisted as long as there remained some litter on the ground. With the final disappearance of the litter only those capable of exploiting the new grassed topsoil habitat remained. These were chiefly *Trichamoeba* sp., *Mayorella vespertilio, Difflugia constricta, Difflugia arcula, Euglypha ciliata, Euglypha rotunda, Trinema enchelys, Trinema lineare* and *Sphenoderia dentata,* all species which have been previously recorded from grassland soils (Stout, 1958, 1960).

Of the ciliates only two species, *Bryophyllum loxophylliforme* and *Stentor multiformis,* were recorded before the burn and not thereafter. These two species were present in the litter and two other species, *Dileptus conspicuus* and *Lecanophrya* sp. (the suctorian epibiont of the copepod *Epactophanes richardi*), were also found only in the litter. Other species, however, appeared to show a preference for the litter habitat. These included *Chilodonella gourandi, Enchelys* sp., *Chilodontopsis muscorum, Spathidium amphoriforme, Spathidium papilliferum, Cohnilembus fusiformis, Frontonia depressa, Tetrahymena pyriformis, Tetrahymena rostrata, Uroleptus* sp., *Onychodromus* sp. and *Euplotes muscicola.* Several species including *Bryometopus pseudochilodon, Psilotricha* sp. and *Aspidisca* sp. appeared more commonly in the forest topsoil cultures, while yet others, notably *Lacrymaria* sp. and *Blepharisma steini* were more common in the grassed topsoil cultures.

Of the other animals, mites were chiefly recorded from the litter and copepods were common only in litter cultures although they did occur in other cultures (doubtless due to the chance survival of eggs) and in one case were recorded from the heavily burnt site together with the associated ciliate epibiont *Opercularia frondicola.* The aquatic oligochaetes, although

clearly preferring the moist litter, were able to survive in both the forest and grassed topsoils (with the exception of *Pristina taita* which did not survive the fire) but the turbellaria, present in all three horizons prior to the burn, occurred only sporadically in later cultures. This was also true of the gastrotrichs and to a lesser extent of the tardigrades but the nematodes and rotifers occurred regularly in all cultures apart from those samples taken immediately after the burn.

DISCUSSION AND CONCLUSIONS

The transition from forest to grassland has clearly a decisive effect on the composition of the microfauna, and, as was shown in the earlier paper (Miller *et al.*, 1955), on the earthworms and arthropod fauna as well. This is not simply due to the annihilation of the fauna by the fire since the greater part of the fauna was recovered in some samples after the burn. Nor is it due simply to an ending of the forest organic cycle for remnants of litter remained some years after the destruction of the forest vegetation. Further, while it is possible to argue that for the larger animals the breaking of the food cycle is critical in many cases this argument is not convincing in respect of the microfauna, most of which are particulate feeders and which can be maintained in cultures free of forest litter. It is difficult to argue that the new grassland topsoil is nutritionally poorer than the forest soil for not only has it a high organic carbon content but the C/N ratio is relatively narrow indicating breakdown of plant material and consequent release of nutrients or their conversion into microbiol and animal tissue. More particularly, for a predominantly bacteriophagous fauna we may note that the aerogenic fermenters, the most acceptable bacterial prey, have remained an important element both in the forest and grassland populations. The differences, therefore, must be attributed to other factors.

Undoubtedly the most important differences are in the physical character of the two environments – the forest litter and the grassland topsoil. These are in respect of moisture capacity, aeration, and temperature. In the soil the moisture is held in small capillaries and pore spaces where aeration may at times be poor. In litter the water is spread in a more continuous film over the surfaces of leaves and twigs and is well aerated. Further the temperatures under a forest cover tend to fluctuate less than in a grassland soil. These differences will account for the failure of the more exacting elements in the forest fauna, such as the copepods and the naidid worm, to survive in the grassland soil. Similarly, the rhizopods which on the whole grow much more slowly than the ciliate protozoa are unable to maintain their population in the soil. The ciliates, however, have preserved a very high population in the grassed topsoil. This may be attributed to several factors. First, the ciliates as a group are better adapted to soil conditions than the rest of the microfauna and secondly the conditions obtaining in this grassed topsoil are especially favourable for two reasons, the relatively high base saturation of the soil and its high content of well decomposed organic material. In this respect the protozoan fauna

of this grassland soil may be compared with that of other grassland soils (Stout, 1958, 1960). The Taita soil is in many respects comparable with the Tekoa soil, previously studied (Stout, 1958). Both are derived from greywacke, have developed under beech forest and have only recently (within the last century) been converted to grassland. The rhizopod population of the Taita grassland soil is very similar to that of the Tekoa soil but the ciliate fauna is very much larger. A large ciliate fauna was recorded from the Omarama soil which has a high base saturation while an increase in the size of the protozoan population was observed in the Taupo soil associated with the conversion of tussock grassland to exotic grassland which was accompanied by an increase in organic matter. It seems, therefore, reasonable to attribute the large ciliate population of the present Taita grassland soil to the associated advantages of high base saturation and high organic content.

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PRELIMINARY NOTE ON THE METABOLISM OF BOUND γ-AMINOBUTYRIC ACID IN ROOT NODULES OF WHITE CLOVER PLANTS

By G. W. Butler, Plant Chemistry Division, J. R. Hulston, Institute of Nuclear Sciences, and R. M. Greenwood, Plant Chemistry Division, Department of Scientific and Industrial Research.

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Summary

Two experiments have been carried out to determine the degree of incorporation of ^{15}N-nitrogen and ^{14}C-glutamic acid respectively into the "bound γ-aminobutyric acid" fraction present in nodules of white clover plants.

With ^{15}N-nitrogen, the labelling pattern observed after exposures of 3·5 hr and 16 hr was glutamic acid > asparagine > "free plus bound γ-aminobutyric acid" > residual nodule N. The rate of nitrogen fixation under the lighting conditions used was about half that calculated from growth data for white clover plants under glass-house conditions.

With ^{14}C-glutamic acid applied in the nutrient solution, labelling of "bound γ-aminobutyric acid" was observed in the nodules and, to a greater extent, in the contiguous root tissue.

Introduction

Butler and Bathurst (1958) reported the presence of γ-aminobutyric acid in bound form in root nodules of plants of the genus *Trifolium*. "Bound γ-aminobutyric acid" was observed in large quantities in nodules of white clover (*T. repens*), the amount ranging up to 1% of γ-aminobutyric acid-N on a dry matter basis.

Two experiments aimed at assessing the importance of "bound γ-aminobutyric acid" in relation to nitrogen fixation were carried out. The hypothesis was that "bound γ-aminobutyric acid" might have a role in the temporary storage of fixed nitrogen. The labelling of this fraction was examined after exposure of white clover to ^{15}N-nitrogen and ^{14}C-glutamic acid respectively.

Experimental

Experiment 1

New Zealand certified white clover plants were grown singly in pots (9 cm diameter) containing pumice of coarse particle size, with periodic applications of "nitrogen-free" nutrient solution. When the plants were approximately 2 months old and growing vigorously, 4 plants were exposed one at a time to an atmosphere (80% nitrogen; 20% oxygen) containing ^{15}N-nitrogen (22·2 ± 1·2 atoms % excess) for periods of 3·5 hr and a further 4 plants were exposed for periods of 16 hr.

The exposures to ^{15}N-nitrogen were made in the apparatus shown in Fig. 1. A glass compartment (C) was held down by rubber straps (not

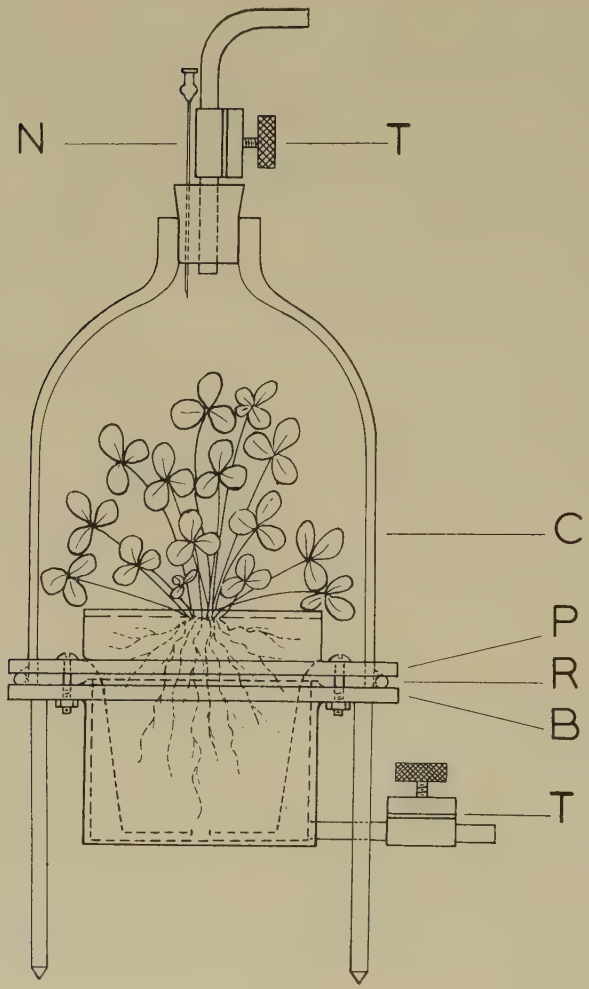

FIG. 1—Apparatus for exposure of white clover plants to an atmosphere containing ^{15}N-nitrogen.

shown in Fig. 1) on to a brass base (B), in which the plastic pot containing the plant was situated. A gas seal was achieved by clamping the silicone-lubricated neoprene O-ring (R) between the brass plate (P) and the base (B). The atmosphere was displaced before and after the experiment by water which was introduced and drained slowly from the base with manipulation of the two taps (T). The carbon dioxide concentration of the atmosphere was raised to 0.15% at the commencement of each exposure by introduction of a known volume of carbon dioxide through

the needle (N). The apparatus was situated in a controlled environment cabinet maintained at a temperature of 18·5°C; the light intensity inside the glass compartment was 1,000 foot candles.

The plants were then freeze-dried and separated into tops, roots and root nodules. The tops and roots from each plant were digested and nitrogen determined by the Kjeldahl procedure. Suitable aliquots were taken for ^{15}N determinations.

The nodules from the 4 plants were combined for the 3·5 hr and 16 hr exposures, giving samples weighing 308 and 363 mg respectively. These samples represented 4·3% and 4·2% respectively of the total dry weight of the plants. These were extracted twice with 20 ml 80% (v/v) aqueous ethanol in a "Teflon" homogeniser and twice with 20 ml distilled water. The four extracts thus obtained were concentrated to dryness under reduced pressure in a rotary evaporator flask kept below 40°C. The residues were taken up in 5 ml water and clarified by centrifugation.

The two alcohol extracts were applied as bands to sheets of No. 3 Whatman filter-paper which had been washed with 0·5% oxalic acid and water according to Bassham and Calvin (1957). These were chromatographed in phenol-water (80 : 20). Narrow strips were cut from the edges of the chromatograms and sprayed with ninhydrin. Zones on the chromatograms corresponding to "asparagine + glumatic acid" and "γ-aminobutyric acid + bound γ-aminobutyric acid" were located and corresponding strips were cut from the sheets and eluted with 10% (v/v) aqueous ethanol. The eluates were concentrated and since the free and bound forms of γ-aminobutyric acid had not separated completely and had been eluted together, these were hydrolysed with 6N HCl for 16 hr at 100°C and excess acid removed by repeated evaporation.

All fractions were applied as bands to acid-washed No. 3 Whatman filter-paper and chromatographed in the upper phase of butanol-acetic acid-water (25:6:25). Guide strips were again cut and sprayed with ninhydrin. Bands corresponding to asparagine, glutamic acid and γ-aminobutyric acid were cut from the sheets and the substances eluted with 10% (v/v) aqueous ethanol. The eluates were concentrated and nitrogen determined by the microkjeldahl procedure. Sufficient ammonium sulphate was added to the neutralised distillates to give 2 mg N for the ^{15}N determinations.

The two water extracts were hydrolysed in 6N HCl for 16 hr at 100°, and the hydrolysates subjected to paper chromatography in phenol-water. No γ-aminobutyric acid was detected when guide strips were sprayed with ninhydrin, indicating that the "bound γ-aminobutyric acid" was probably completely extracted with 80% (v/v) aqueous ethanol (c.f. Butler and Bathurst, 1958). No further fractionations of these extracts were therefore made.

The nodule residues after ethanol and water extractions were digested and nitrogen estimated by the microkjeldahl procedure. The ^{15}N enrichments were determined on suitable aliquots of the neutralised distillates.

Nitrogen-15 analyses were made on the mass spectrometer described by Hulston and Shilton (1958). The nitrogen was evolved from the samples

in Ritterberg tubes using the standard hypobromite method. For convenience, the double collector system was used for the ratio determinations, although this was not necessitated by the enrichments obtained. Both the controls and the samples were measured relative to a flask of cylinder nitrogen. The oxygen and argon peaks were checked in each case to establish the absence of contamination with air.

EXPERIMENT 2

A white clover plant from the same batch as used for Experiment 1 was taken and the root system carefully separated from the pumice and placed in "nitrogen-free" nutrient solution. One well-nodulated root was disentangled from the main root system and introduced into a small test-tube containing 2 ml of "nitrogen-free" nutrient solution and 1 μc (0·1 μM) generally-labelled glumatic acid. The plant was placed in a controlled environment cabinet for 16 hr in light of 2,000 foot candles intensity.

The nodulated root exposed to ^{14}C-glutamic acid was freeze-dried and dissected into rootlets (4·6 mg) and nodules (5·2 mg). These were extracted at room temperature in a "Teflon" homogeniser with 10 ml 80% (v/v) aqueous ethanol, followed by 10 ml distilled water. The extracts were taken to dryness and the residues dissolved in 1 ml water. All samples were then applied to sheets of acid-washed Whatman No. 1 filter-paper and subjected to two-dimensional chromatography in phenol-water (80 : 20) followed by the upper phase of butanol-acetic acid-water (25 : 6 : 25). Radio-autographs were prepared using Kodak Screen X-ray film with exposures of 14 days. The radioactivity in compounds thus located was determined by counting directly off the paper using a Geiger-Müller tube with mica end-window (Phillips 18506). The compounds were identified by spraying the chromatograms with ninhydrin reagent.

A similar experiment was also carried out using a *Lotus uliginosus* plant.

RESULTS

EXPERIMENT 1

In Table 1 are shown the amounts of N recovered and the ^{15}N enrichments found for "free plus bound γ-aminobutyric acid", asparagine, glutamic acid and for the residual nodule N after ethanol and water extraction. It will be noted that the amount of γ-aminobutyric acid recovered from these nodules was considerably less than the levels found by Butler and Bathurst (1958) for nodules of white clover plants growing in the field. Asparagine was recovered at levels comparable with those previously observed.

The ^{15}N enrichment was greatest for glutamic acid after 3·5 hr; insufficient glutamic acid was recovered from the 16 hr sample to enable a ^{15}N determination to be made. Asparagine was markedly enriched and "free plus bound γ-aminobutyric acid" also showed a moderate enrichment. The residual nitrogenous fraction had a very much smaller enrichment for both exposure times.

TABLE 1—Levels of N Recovered and the ^{15}N-Enrichments Found for Various Root Nodule Fractions After Exposure of Clover Plants to ^{15}N-Nitrogen

Exposure	3·5 hr		16 hr	
Fraction	N (mg %)	Atoms % Excess*	N (mg %)	Atoms % Excess*
Free + bound γ-aminobutyric acid	68	2·4 ± 0·5	56	3·5 ± 0·2
Asparagine	188	9·4 ± 0·7	166	13·6 ± 1·0
Glutamic acid	16	13·8 ± 2·1	<1	—
Residue	3,800	0·1 ± 0·01	4,040	0·6 ± 0·05

*Enrichment of ^{15}N-nitrogen was 22·2 ± 1·2 atom % excess.

From the ^{15}N data for the roots, shoots and nodule fractions the amount of N fixed by the clover plants during the exposure periods could be calculated. It was found that the plants fixed 0·54% of their own content of nitrogen in 3·5 hr and 3·5% of their N content in 16 hr; 29·2% and 8·2% respectively of this fixed nitrogen was present in the nodules.

EXPERIMENT 2

The radioactivities found in various compounds are shown in Table 2. It will be noted that free γ-aminobutyric acid was appreciably labelled in both ethanol extracts and that "bound γ-aminobutyric acid" was labelled in all extracts except the ethanol extract of nodules.

TABLE 2—Distribution of ^{14}C in Various Compounds After Exposure of a Nodulated White Clover Root to Generally-labelled ^{14}C-Glutamic Acid. Values are Expressed as Observed Counts per Minute

	Root Extracts		Nodule Extracts	
	Ethanol	Water	Ethanol	Water
Origin	99	137	52	42
Aspartate	20	—	8	—
Glutamate	23	—	20	—
Asparagine	18	—	32	—
Alanine	13	—	26	—
Leucine	1	—	6	—
Valine	5	—	12	—
γ-Aminobutyric acid	81	—	100	—
Bound γ-aminobutyric acid	74	37	—	16

In the experiment with a *Lotus uliginosus* plant, labelling of γ-aminobutyric, citric, malic and succinic acid was observed in radioautographs of the ethanol extracts. Traces of radioactivity were observed in the position on the chromatograms corresponding to "bound γ-aminobutyric acid" for the ethanol extract of the roots and for the water extracts of roots and nodules. Insufficient labelling had taken place for it to be practicable to determine whether γ-aminobutyric acid was liberated on hydrolysis with 6N HCl.

DISCUSSION

Although this work is at a preliminary stage it is clear that free and bound γ-aminobutyric acid were sufficiently rapidly labelled by both ^{15}N-nitrogen and ^{14}C-glutamic acid to warrant further investigations of the role of "bound γ-aminobutyric acid" in the fixation of nitrogen by white clover.

The marked ^{15}N-labelling of the small amount of glutamic acid present after 3·5 hr is consistent with other observations on nitrogen fixation (Wilson and Burris, 1953; Nason and Takahashi, 1958) and the metabolism of ammonia in plant tissues (Webster, 1959). The extensive ^{15}N-labelling of asparagine is in agreement with the observations of Turchin (1959), who found that most of the ^{15}N present in the nodule cell sap of lucerne, pea, red clover and yellow lupin plants exposed to ^{15}N-nitrogen occurred in the amide group of asparagine.

The detection of ^{14}C-labelled "bound γ-aminobutyric acid" in white clover root tissues was unexpected, in view of it having been detected in nodule tissue only in the earlier work of Butler and Bathurst (1958). Detection by radioactive labelling can be considerably more sensitive than detection by chemical means, depending on the size of the metabolic pool for the substance in question. It is also possible that the greater labelling of "bound γ-aminobutyric acid" in the root tissues than in the nodules was a consequence of the ^{14}C-glutamic acid being applied in the nutrient solution rather than at the sites of nitrogen fixation in the nodules.

The rates of nitrogen fixation calculated from the ^{15}N enrichments are approximately half those calculated from growth rate data for white clover plants growing in pots under glasshouse conditions. In this connection it is probably relevant that the light intensity inside the apparatus shown in Fig. 1 was one-tenth that of normal sunlight.

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THE TICKS (ACARINA : IXODOIDEA) OF SEA BIRDS IN NEW ZEALAND WATERS

By L. J. DUMBLETON, Entomology Division, Department of Scientific and Industrial Research, Christchurch.

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Summary

The male of *Ixodes eudyptidis* Maskell is described for the first time, and the New Zealand population of *I. auritulus* Neumann is raised to subspecific rank as *zealandicus* sub-sp. nov. The affinities of these two species are discussed, and new host and locality records are presented.

INTRODUCTION

The ticks of sea birds in the southern oceans have been treated in recent years by Zumpt (1952); Dumbleton (1953, 1958); Arthur (1955a, 1955b, 1958, 1960a, 1960b); and Roberts (1960).

The species that are currently recognised as present in the southern oceans are listed below.

ARGASIDAE

Ornithodoros capensis Neumann – coasts of South Africa, Australia, and New Zealand; also Northern Hemisphere.

IXODIDAE (* = species whose males are unknown)

Ixodes auritulus Neumann – discussed below.

* *diomedeae* Arthur – Nightingale Island, Tristan da Cunha.

eudyptidis Maskell – New Zealand, ?Australia (Little Green Is.).

kergulenensis André & Colas-Belcour – Kergulen Is., Heard Is.

kohlsi Arthur – Australia (South coast).

* *percavatus* Neumann – Tristan da Cunha.

* *pterodromae* Arthur – Marion Is., Macquarie Is., Tasmania.

uriae White – New Zealand, Australia, South Africa, South America, etc.; also Northern Hemisphere.

* *zumpti* Arthur (a possible synonym of *kergulenensis*) – Nightingale Is., Tristan da Cunha, ?Heard Is.

The males of the species in which this sex is known have been collected only in the nests, where mating probably occurs, and not on the hosts. Taxonomically, the four species in New Zealand waters are now known in all stages, but little is known of their ecology.

Ornithodoros capensis Neumann. This is the only argasid tick in New Zealand waters and in the southern oceans. It lives in the nest, visits the host only to feed, and leaves it when engorged. The dispersal of this tick is presumably due to chance carriage of ticks which have failed to leave the host before flight. There is nothing to be added to the previous paper (Dumbleton, 1958) except a record which shows that the species is established on the East coast of the South Island as well as on the West coast, from which it was originally recorded.

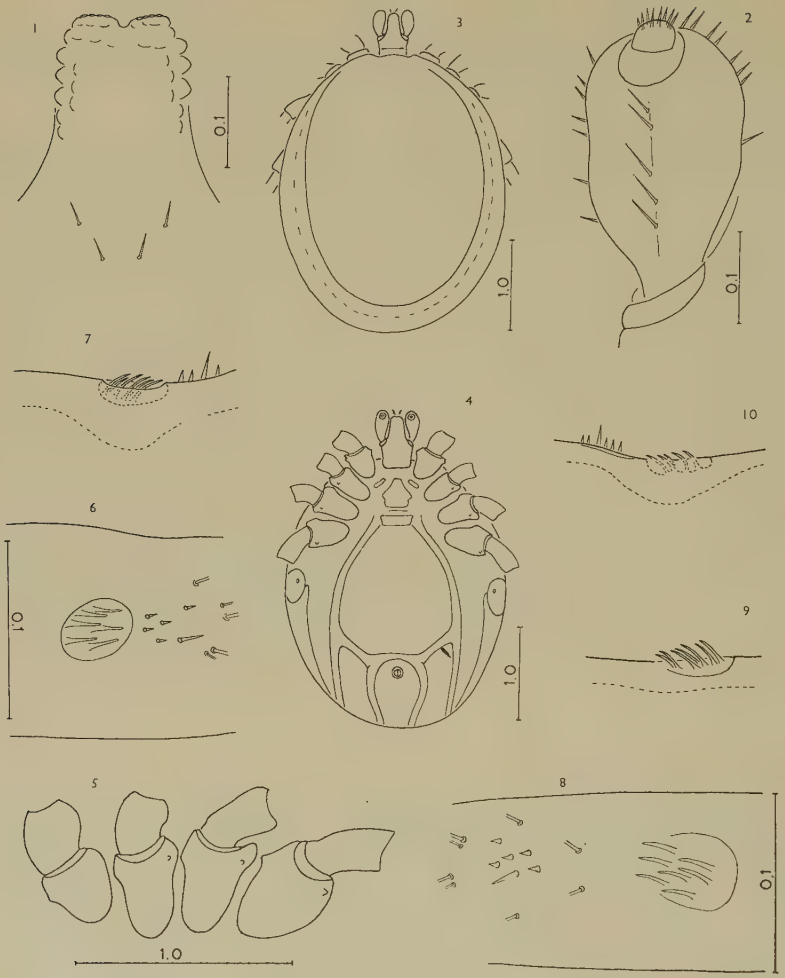
Ixodes uriae White. In general this species appears to breed in greatest density in the subantarctic, and to occur in New Zealand on straggler birds of species which, for the most part, do not breed in New Zealand. One of the new records shows that it does breed on the New Zealand coast however. The wide distribution of this species, its wide host range, and the absence so far of recognisable sub-species, argues both unusual specific stability and successful adaptation to its unspecialised host relations. Zumpt (1952) has cited the migrations of Wilson's Storm Petrel from South to North, and those of the Arctic Tern from North to South, as possible agents in the dispersal of *uriae* between the hemispheres.

Ixodes eudyptidis Maskell

SYNONOMY. The placing of *eudyptidis* as a synonym of *uriae* by Cooley and Kohls (1945) was an uncorrected error, apparently followed by Zumpt (1952). *Ixodes neumanni* Nuttall and Warburton 1911, from an undetermined host in New Zealand, was later considered by these authors to fall in the synonomy of *eudyptidis*. Arthur (1956) restored it to specific rank, figuring the fore-tarsus and Haller's organ. While this latter tends to have more of a closed capsule than the typical *eudyptidis* figured by Arthur (1955a), it is doubtful whether this is a reliable distinction in the absence of other characters. Roberts (1960) considered that the species should remain as a synonym of *eudyptidis* and there is no evidence from New Zealand specimens to suggest that two closely related species are concerned.

The species is confined to the New Zealand region, with the exception of Roberts' (1960) recent record from Little Green Island, Australia. The specimens were noted to differ in some respects from typical *eudyptidis*. Earlier records of *eudyptidis* from Australia are now doubtful.

The male, until now, has been unknown and its discovery helps to clarify the relationship between *eudyptidis* and *kohlsi*.



FIGS 1–10. (Scale in mm.)

(1) *Ixodes eudyptidis*, male: hypostome, ventral.
(2) ,, ,, ,, palp, ventral.
(3) ,, ,, ,, body & scutum, dorsal.
(4) ,, ,, ,, body & ventral plates, ventral.
(5) ,, ,, ,, coxae & trochanters.
(6) ,, ,, ,, Haller's organ, dorsal.
(7) ,, ,, ,, Haller's organ, lateral.
(8) *Ixodes auritulus zealandicus*, male: Haller's Organ, dorsal.
(9) ,, ,, ,, ,, Haller's organ capsule, lateral.
(10) ,, ,, ,, female: Haller's organ, lateral.

Ixodes eudyptidis Maskell – DESCRIPTION OF MALE (Figs 1–7)

BODY: oval, length including capitulum 3·5 mm, greatest width 2·5 mm about mid-length. Colour castaneous. Without prominent punctation or hairs.

CAPITULUM: basis capituli 0·3 mm wide, sides sub-parallel, widest immediately behind palp; dorsally with a group of about 12 pits on each side anterior to the transverse carina which separates neck, cornua absent; ventrally with a group of 6–8 short setae on each side and transverse row of pits anterior to these; auriculae absent.

HYPOSTOME (Fig. 1): with small apical notch or emargination; dentition extending to half-length, dentate portion not longer than wide, 3 or 4 coronal plates on each side followed by traces of two rows of obsolete teeth; lateral margins with two crenulations basad of corona followed by three larger conical teeth and two rounded teeth; two or three smaller rounded teeth mesad of the largest teeth. Dentition 2/2.

PALPI (Fig. 2): first segment short annular; 2nd and 3rd indistinctly divided slightly distad of half-length, broad, flattened dorsally, abruptly narrowed at base, rounded apically, neither upturned nor bent ventrally, ventrally with a longitudinal carina which bears a row of setae; 4th segment short; thumb-like rounded apically.

SCUTUM (Fig. 3): oval, length 2·75 mm, width 1·8 mm, castaneous, shining, without evident punctation or hairs; scapulae small rounded; cervical grooves faint; sub-lateral groove and marginal fold prominent.

VENTRAL PLATES (Fig. 4): impunctate castaneous, with few hairs and those short and not prominent. Pre-genital plate sub-hexagonal. Jugular plates oblique, transverse, sub-rectangular. Post-genital plate transverse. Median plate length 1·3 mm, slightly longer than wide. Anal plate rounded anteriorly, narrowed posteriorly to only half the greatest width. Ad-anal plates as wide posteriorly as anteriorly, narrowed in anterior half. Epimeral plates with narrow process reaching half-length on mesal margin of spiracular plate.

GENITAL OPENING: between third coxae.

ANAL GROOVE: horseshoe-shaped, converging posteriorly.

SPIRACULAR PLATE: 0·35 mm long, oval, macula slightly anterior and ventrad of centre.

LEGS: trochanters all without spurs; coxae 1 without external spur posteriorly, small external saliences on coxae 2, 3 & 4 (Fig. 5), most prominent on 4; tarsus 1 not abruptly humped, Haller's organ (Figs 6 & 7) with concave capsule similar to that of female, without dorsal hairs between capsule and trough, trough adjoining capsule.

SPECIMENS EXAMINED: 4 males, 3 females (2 engorged, one with eggs extruded).

LOCALITY: South of Paturau R., coast of West Nelson, South Island, New Zealand.

COLLECTOR: J. I. Townsend, 24/X/60.

REMARKS: "On dry sandy floor of cave previously occupied by Little Blue Penguin, *Eudyptula minor* (Forster)".

This male is quite distinct from *I. kohlsi* Arthur, the characteristic tick of *E. minor* in Australian waters, more especially in the dentition of the hypostome and the absence of downward curvature of the apex of segment 3 of the palps.

In very few cases are ioxdid males and females correlated by the rearing of both sexes from the eggs or from identifiable nymphs. In most cases presumptive correlation is based on association of the two sexes on the host or in the nest. The morphological characters common to males and females are few and often do not differ greatly between species. The females collected with the male described above were *I. eudyptidis,* and as *E. minor* is the only sea-bird on the New Zealand coast which nests at ground level in coastal caves there seems little reason to doubt either the host association or the correlation of the sexes. The following male characters are consistent with those of the female: broad palpi, abruptly narrowed basally and with indication of division between segments 2 and 3 at mid-length; anal groove constricted posteriorly; capsule of Haller's organ concave.

FEMALE

Recent descriptions of the female were given by Dumbleton (1953) and Roberts (1960). It is distinguished from that of *I. kohlsi* by the absence of the cornua, the transverse non-retrograde posterior margin of the auricula, and the absence of a closed capsule in Haller's organ.

One of the two female specimens from Broken River had fused porose areas on the dorsum of the basis capituli, a condition which was recorded earlier (Dumbleton, 1953) for another specimen.

EGG: Ovoid, 0·5 mm long, 0·4 mm wide, light yellowish brown.

HOST RELATIONS: The date of collection of the gravid female coincides with the period during which the birds are on the nests incubating the eggs, and before the adults and young leave the nests. Larvae have been taken on a shag in the same month, and on a penguin in December. The existing host records for *eudyptidis* indicate that it is unspecialised in its host relations. *Eudyptula minor* is a frequent and apparently a characteristic host, but it occurs on a range of other sea-birds (Dumbleton, 1953), as well as on the Black Shag, *Phalacrocorax carbo* (L.), and in the nests of the inland colonies of this latter host. There is a single record from a burrow-nesting host, *Pterodoma cooki* (Gray). The Little Blue Penguin is frequently a solitary nester, in caves and crevices rather than in burrows, but preferred nesting sites are constantly reoccupied. In suitable soils the species may use burrows, and this habit may have been more common before the modification of coastal habitats by European occupation.

It is of interest that *I. kohlsi,* which occurs characteristically on *E. minor,* in a restricted area in Australia, is apparently not closely related to *eudyptidis.* It also is not recorded from burrowing hosts except where the nesting areas overlap (Roberts 1960), and is also recorded from a shag. It would appear that the penguin ticks of Australia and New Zealand did

not arise from the same stock in parallel with the subspeciation of the host, but that in the two areas ticks of different stocks have been able to capitalise on the availability of the same host. The absence of significant overlap in the distribution areas of the two species indicates that little interchange of hosts occurs between the two areas, or that what there is is not effective in bringing about permanent colonisation by the ticks.

Two records from Black Shag are of birds which were unable to fly, and the penguins and other sea birds found dead or dying on the beaches are often tick-infested, especially on the head and neck. It is probable that this tick, especially when attached near the brain or spinal cord of the neck, produces a tick paralysis. A similar paralysis, caused by the injection of a neurotoxin from the salivary glands of females of *Ixodes holocyclus* Neumann, results in mortality of both man and animals in Australia (Roberts 1960).

Ixodes auritulus Neumann (*sens. lat.*)

This species has, in the past, frequently been recorded from the southern oceans. Arthur (1960a) has studied the forms of this species which exist in North and South America. The host of the type of *I. auritulus* (*sens. str.*) from Punta Arenas is unknown. The other records of the species from both Americas are exclusively from land-birds. Arthur (1960a) has reinstated *I. percavatus* Neumann, previously in synonymy with *auritulus,* and described two new species, *zumpti* and *pterodromae,* which fall in the *percavatus* species group. Both are described from females only and he suspected that females taken with males of *kergulenensis* on Heard Island were *zumpti.*

The effect of the new species described by Arthur and the recognition of *pterodromae* in Macquarie Is. and Tasmania by Roberts, is to narrow the distribution of *"auritulus"* on sea birds in the southern oceans. The principal remaining area is the New Zealand region and Arthur (1960a) has pointed out characters which distinguish this population from *auritulus* (*s.s.*) and from other forms of *auritulus.* Since the New Zealand form occurs solely on seabirds there are grounds for considering it to be distinct, certainly at a subspecific level, and probably, when the males of *auritulus* (*s.s.*) are known, at a specific level.

The New Zealand population on sea birds is here recognised as a distinct sub-species. The male, female, nymph and larva were described by Dumbleton (1953), and the first three stages were re-described by Arthur (1960a) and only the diagnostic characters are given here.

Ixodes auritulus Neumann *zealandicus* sub-sp. nov.

FEMALE: Coxae 2 & 3 longer and narrower than in typical sub-species. Length-width ratio of coxae 3, measured at mid-length of long and short axes at right angles to each other, is 1·7 – 1·8 as against 1·1 – 1·2 in typical sub-species. In most specimens internal spur on coxa 1 not prominent and postero-internal saliences on coxae 2 & 3 rounded as opposed

to acute saliences in typical sub-species. Haller's organ with concave capsule. Segment 1 of palp with anterior mesal process attenuated and with salient meso-dorsal ridge.

MALE: Haller's organ (Figs. 8 & 9) with superficial type capsule; trough distant from capsule.

HOLOTYPE: male, deposited in Dominion Museum.

LOCALITY: Snares Is., South of New Zealand.

HOST: *Pelecanoides urinatrix* (Gmelin), Diving Petrel (ex nest material).

COLLECTOR: R. A. Falla, –/XII/47.

PARATYPES: 1 female & 1 nymph, same data as holotype.
1 male, deposited in Entomology Division, ex faeces of *Sphenodon punctatus* Gray, Stephen Island, Cook Strait, coll. E. S. Gourlay, 1933.
3 females & 2 nymphs, deposited in Entomology Division, ex *Pachyptila turtur turtur* (Kuhl), Stephen Is., coll. E. S. Gourlay, 1933.
1 female deposited in Entomology Division, ex *Puffinus griseus* (Gmelin), Birdling's Flat, Banks Peninsula, coll. J. R. Jackson, 17/V/59.

The male from the Snares Is. was associated with a female of *"auritulus"*. The discovery of the amply-distinct male of *eudyptidis* removed the possibility, which arose because the locality is near the southern limit of *eudyptidis* distribution, that the male could have been that of *eudyptidis*. The correctness of the correlation is confirmed by the association of identical males and females on Stephen Is. These were not from the same hosts, but from the same burrows, where the lizard and the bird live commensally. The burrows were 600 ft above sea level, and Mr Gourlay informs me that no penguins were ever seen at that level. The form of the palps and of the anal grooves correspond in males and females.

STRUCTURE OF HALLER'S ORGAN: Arthur (1956) cited distinctive sexual dimorphism in only two of the species he studied. The superficial (exposed) condition of the sensory hairs of the capsule was seen only in the male of *kergulenensis*, and this species was unique in having a hair between the capsule and the trough (Arthur, 1955b).

In *I. auritulus zealandicus* there is a pronounced sexual dimorphism in the structure of Haller's organ. The capsule of the male (Figs 8 & 9) is of a superficial type closely approximating that of *kergulenensis*, including the hairs between capsule and trough. That of the female is of the concave type (Fig. 10). The males of *kergulenensis* and *zealandicus* are alike in the structure of Haller's organ, and in the type and disposition of the teeth on the hypostome, though they differ in the armature of the coxae. It is therefore possible that the females taken with males of *kergulenensis* on Heard Is., even if differing in Haller's organ, may have been *zumpti* as Arthur suspected, and that *zumpti* is the female of *kergulenensis*.

HOST RELATIONS: The existing records of *auritulus* from southern oceans, if one excludes earlier records from Macquarie Is. and Antipodes Is. as possibly *pterodromae*, are exclusively from burrow-nesting birds in the New Zealand area. It is difficult to demonstrate any host specificity or host-preference without systematic information on the frequency and density of infestation on different hosts nesting in the same area. Where records are few there is no way of deciding whether association with any individual host is a constant and significant one or merely casual. On the Snares Is., the type locality for *zealandicus*, no specimens were encountered among the very numerous specimens of *uriae* taken from the nest of the penguin *Eudyptes robustus* Oliver. This and other islands where there is a high density of several birds of different nesting habits would offer opportunities for a study of host-preferences in the ticks that occur there.

The situation in New Zealand appears to be paralleled on Heard Is. Here the only records of *kergulenensis*, which is undoubtedly closely related to *zealandicus*, are from two host species belonging to the same burrow-nesting genera as in New Zealand. Extensive collections from four other potential host species on Heard Is. yielded only *uriae* (Zumpt, 1952).

Burrow-nesting hosts, even if not in high density would increase the probability of host-finding by the tick, because of the constant reoccupation of the burrows and the confined space and enforced intimacy in the burrow itself. Burrows may also be important in reducing tick mortality, caused by both climate and predation, during the period when the nests are unoccupied.

In the case of *kergulenensis* and *zealandicus* speciation in the ticks appears to have paralleled the speciation by isolation in the hosts.

Although one of the New Zealand hosts of *zealandicus* (*Puffinus griseus*) migrates to the Northern Hemisphere the tick is not recorded there and it would appear that carriage of the tick outside the area or hemisphere in which nesting occurs, whether by regular migration or by stragglers, is seldom followed by permanent colonisation of the tick. An investigation of the tick parasites of immigrant godwits in New Zealand may prove instructive in this connection.

KEY TO THE KNOWN MALES OF *Ixodes* ON SEA-BIRDS IN SOUTHERN OCEANS

1. Coxae unarmed; five hair-tufts on posterior body-margin; palpal segment 3 pointed apically and upturned ..... *uriae* White.
   Coxae armed; no hair-tufts posteriorly; 3rd palpal segment not pointed or upturned 2
2. Hypostomal teeth reduced in number, 2–3 on each side; 3rd palpal segment bent ventrad apically; Haller's organ capsule closed ..... *kohlsi* Arthur.
   Hypostomal teeth more numerous; 3rd palpal segment not bent ventrad apically; Haller's organ capsule not closed 3

3. Toothed area of hypostome short sub-circular, dentition 2/2; 3rd palpal segment abruptly narrowed basally; Haller's organ with concave capsule ..... *eudyptidis* Maskell.

   Toothed area of hypostome long, extending towards base on each side, dentition 4/4; 3rd palpal segment gradually narrowed basally; capsule of Haller's organ superficial 4

4. Dorsal ridge anterior to neck transverse, straight; coxae 3 & 4 with small conical saliences and a larger spur postero-externally; anal groove with straight diverging sides ..... *auritulus zealandicus* sub-sp. nov.

   Dorsal ridge strongly curved caudad in median line; coxae 3 with small conical salience, larger spur absent; coxae 4 with neither salience nor spur, anal groove arcuate, converging at margin ..... *kergulenensis* André & Colas-Belcour.

HOST AND LOCALITY RECORDS
(additional to Dumbleton, 1953)

ARGASIDAE

Ornithodoros capensis Neumann

Stictocarbo punctatus punctatus (Sparrmann). Spotted Shag.

Birdling's Flat, Banks Peninsula, *ex nests*, with *I. eudyptidis* and *I. uriae*, L.J.D., 24/XI/57; J. R. Jackson, 24/XII/57.

IXODIDAE

Ixodes anatis Chilton

Apteryx mantelli Bartlett. Kiwi.

Little Barrier Is., *ex* dead male, J. S. Watson.

Felis catus L. Cat.

Little Barrier Is., *ex faeces*, J. S. Watson.

Ixodes auritulus zealandicus Dumbleton

Puffinus griseus (Gmelin). Sooty Shearwater.

Birdling's Flat, *ex* dead bird, J. R. Jackson, 17/V/59.

Ashburton, *ex* dead bird, B. Stonehouse, 18/V/61.

Ixodes eudyptidis Maskell

Stictocarbo punctatus punctatus (Sparrman). Spotted Shag.

Birdling's Flat, *ex* nest, with *O. capensis* and *I. uriae*, J. R. Jackson, 24/XII/57; L.J.D., 24/XI/57.

New Brighton, *ex* dead bird, J. R. Jacskon, 18/VIII/57.

Perpendicular Point, *ex* nests, with *O. capensis*, J. R. Jackson, –/IX/57.

Larus dominicanus Lichtenstein. Black-backed Gull.

Monaco, R. Harley, 29/I/53.

Kapiti Is., J. C. Davenport, 31/XII/57.

Otago Peninsula, no data.

Phalacrocorax carbo (L.). Black Shag.

Broken R., 7/IX/33.

Eudyptula minor (Forster). Little Blue Penguin.

Paturau R., *ex* nest, J. I. Townsend, 24/X/60.

Ixodes uriae White

Stictocarbo punctatus punctatus (Sparrmann). Spotted Shag.

Birdling's Flat, *ex nests,* with *O. capensis* & *I. eudyptidis,* L.J.D., 24/XI/57; J. R. Jackson, 24/XII/57.

Eudyptes robustus Oliver. Snares Crested Penguin.

Snares Is., *ex* nests, Canterbury Univ. Exped., –/I/61.

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ALEYRODIDAE (HEMIPTERA : HOMOPTERA) FROM THE SOUTH PACIFIC

By L. J. DUMBLETON, Entomology Division, Department of Scientific and Industrial Research, Christchurch.

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Summary

The Aleyrodidae recorded from the South Pacific, exclusive of New Caledonia, are mostly not endemic. The localities and the food plants from which the species are recorded are listed, and a key to the species is given.

INTRODUCTION

The Aleyrodidae of New Caledonia have been recently reviewed by the author (1956, 1961) and by Cohic (1959). The present paper lists the Aleyrodidae of the remaining part of the South Pacific area, in so far as these are recorded. The fauna of New Guinea, the Solomon Islands and New Hebrides is practically unknown, and little is known of the Chilean fauna except for the few species described by Moles and Baker (1921).

The aleyrodid fauna of the area under consideration is small and consists mainly of species which are not endemic and possibly introduced. Further collecting may, however, increase the number of known endemic species in Fiji. Little affinity is demonstrable between the aleyrodid fauna of the South Pacific and those of adjoining areas, other than the occurrence in Tonga of an endemic species of *Orchamoplatus*, a genus which is centred in New Caledonia. *Orchamoplatus* is not recorded in Micronesia (Takahashi, 1956) which has a small fauna of four endemic and four widely distributed species. Only two of these latter occur in the South Pacific area.

SPECIES LIST, LOCALITIES AND FOOD PLANTS

(x = type locality for species described from the area)

Sub-family UDAMOSELINAE

Aleurodicus holmesii (Maskell)

x Fiji — *Psidium sp.* — Maskell, 1890.

(Note: Duplicate material in the Maskell collection enables me to confirm the identity of Maskell's species with the specimens from Java described by Quaintance and Baker (1913).)

Sub-family ALEYRODINAE

Aleurocanthus calophylii (Kotinsky)

x Fiji (Levuka) — *Calophyllum inophyllum* L., Kotinsky, 1907.

(Sigatoka) — *Calophyllum inophyllum* L., L.J.D.

Aleurotrachelus trachoides (Back)

Tahiti	*Capsicum annuum* L., Cohic, 1955.
	Datura sp., Coll., Cohic.
	Dioscorea sp., Coll., Cohic.
Rangiroa	*Bidens pilosa* L., Coll., Cohic.

Bemisia leakii (Peal)

Fiji	undetermined, Kotinsky, 1907.
Tahiti	*Colocasia esculenta* L., Cohic, 1955.
	Erythrina sp., Coll., Cohic.

Dialeurodes fijiensis (Kotinsky)

x Fiji (Rewa)	undet. Leguminosae, Kotinsky, 1907.

Dialeurodes kirkaldyi (Kotinsky)

Tahiti	*Morinda citrifolia* L., Coll., Cohic.
Bora Bora	*Gardenia tahitiensis* De Candolle, Coll., Cohic.

Neomaskellia bergii (Signoret)

Fiji	*Saccharum officinarum* L., Maskell, 1896.
Tahiti	*Saccharum officinarum* L., Cohic, 1955.
Rarotonga	*Saccharum officinarum* L., L.J.D.
Mauke	*Saccharum officinarum* L., L.J.D.
Vella Lavella	*Saccharum officinarum* L., L.J.D.

Neomaskellia comata (Maskell)

x Fiji	undet. Graminaceae, Maskell, 1896.

Orchamoplatus mammaeferus (Quaintance and Baker)

Samoa	*Codiaeum* and *Citrus* spp., Dumbleton, 1956.
Rarotonga	*Codiaeum* and *Citrus* spp., Dumbleton, 1956.
Tahiti	*Codiaeum* and *Citrus* spp., Dumbleton, 1956.
Fiji	*Codiaeum* and *Citrus* spp., Dumbleton, 1956.

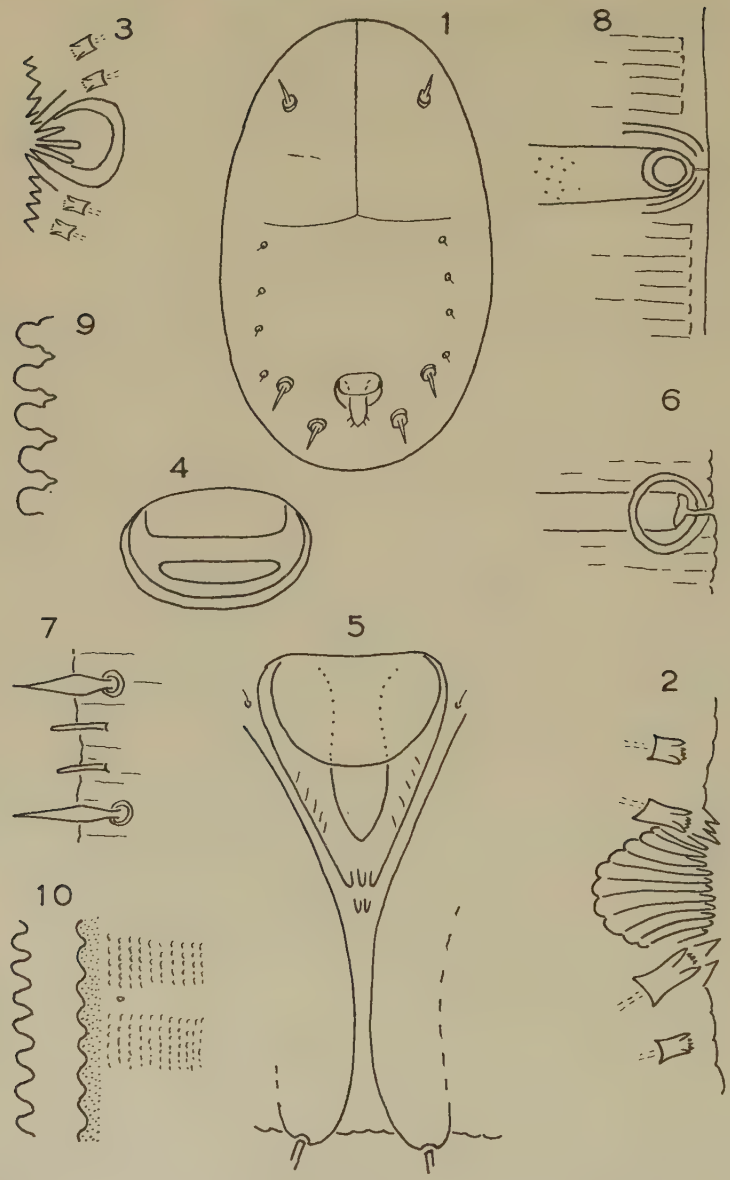
Orchamoplatus calophylli Russell

Tonga (Vavau) *Calophyllum* sp., Russell, 1958.

KEY TO SPECIES (based on pupae)

1. Compound wax pores present (*Udamoselinae*); 7 pairs (Fig. 1), 2 pairs caudal and 1 pair cephalic larger, with longer entire central process (*Aleurodicus*); lingula long exserted, with 2 pairs prominent hairs; marginal teeth broadly rounded ..... *A. holmesii*
   Compound wax pores absent (*Aleyrodinae*) 2

2. Submarginal row of exserted gland orifices (papillae) (*Orchamoplatus*) (Figs 2 and 3) 3
   Not as above. 4



FIGS—1. *Aleurodicus holmesii,* compound pores and vasiform orifice. 2. *Orchamoplatus mammaeferus,* thoracic tracheal comb and gland orifices. 3. *Orchamoplatus calophylli,* thoracic tracheal comb and gland orifices. (After Russell.) 4. *Neomaskellia bergii,* vasiform orifice, operculum and lingula. 5. *Bemisia leakii,* vasiform orifice and anal furrow. 6. *Dialeurodes fijiensis,* thoracic tracheal pore. (After Quaintance and Baker) 7. *Dialeurodes fijiensis,* vasiform marginal setae. (After Quaintance and Baker.) 8. *Dialeurodes kirkaldyi,* thoracic tracheal pore. 9. *Aleurocanthus calophylli,* marginal teeth. 10. *Aleurotrachelus trachoides,* marginal and submarginal teeth.

3. About 10 apically-rounded teeth in thoracic tracheal comb (Fig. 2); pale species ..... *O. mammaeferus*
Four to six apically-acute teeth in comb (Fig. 3); black species ..... *O. calophylli*

4. Vasiform orifice, lingula and operculum wider than long (Fig. 4); cephalic and 8th abdominal setae long (*Neomaskellia*) 5
Not as above 6

5. Sixteen pairs of submarginal hairs of sub-equal length; hairs of first abdominal segment long ..... *N. bergii*
Twelve pairs of submarginal hairs, the two cephalic pairs shorter; hairs of first abdominal segment short or absent ..... *N. comata*

6. Vasiform orifice long, narrow, pointed posteriorly; anal furrow present (*Bemisia*) (Fig. 5). ..... *B. leakii*
Not as above 7

7. Tracheal pores present (*Dialeurodes*) (Figs 6 and 8) 8
Tracheal pores absent; black species 9

8. Submarginal setae vasiform (Fig. 7); vasiform orifice not toothed; brown species ..... *D. fijiensis*
Submarginal setae absent; vasiform orifice toothed; pale species with median thoracic pigmentation ..... *D. kirkaldyi*

9. Marginal teeth in single row (*Aleurocanthus*), somewhat knobbed (Fig. 9); 40 or more long spines on dorsum ..... *A. calophylli*
Marginal teeth in double row (*Aleurotrachelus*), not knobbed (Fig. 10); without spines on dorsum ..... *A. trachoides*

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THE COUPLED DIFFUSION OF HEAT AND MOISTURE IN BALED WOOL

Part 1. CHANGES IN BALE TEMPERATURE

By I. K. WALKER, Dominion Laboratory, Department of Scientific and Industrial Research, Wellington.

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Summary

Experiments are described in which changes in ambient temperature of up to 49°C were suddenly applied to bales of raw wool, over a range of temperatures. It is shown that the subsequent central temperature changes in the wool are in general accord with Henry's theory for the coupled diffusion of heat and of moisture. A method is described for suppressing the slow temperature wave in baled wool, and it is shown that the diffusion of heat is then faster than would be predicted for the case where there is no coupling. Values of σ and ω for wool are presented over a range of temperature and regain. The significance of these results is discussed in relation to the problem of spontaneous ignition of pie wool.

SYMBOLS AND UNITS

T	temperature	°C
$\triangle_o T$	suddenly applied change in external temperature	°C
$\triangle T$	consequent change in temperature within wool bale	°C
C	water vapour concentration in atmosphere	g cm^{-3}
$\triangle_o C$	suddenly applied change in concentration of water vapour in external atmosphere	g cm^{-3}
$\triangle C$	consequent change in concentration of water vapour in atmosphere within wool bale	g cm^{-3}
M	water content of greasy wool expressed as fractional weight of clean dry wool	
$\triangle_o M$	ultimate change in water content of wool within bale resulting from $\triangle_o T$ and $\triangle_o$C	
$\triangle M$	change in water content of wool within bale at some intermediate time (resulting from $\triangle_o T$ and $\triangle_o$C)	
ρ	bulk density of greasy wool	g cm^{-3}
γ	mass of bulk greasy wool containing unit air volume (cf. Henry, 1939)	g cm^{-3}
c	specific heat of greasy wool	cal g^{-1} °C^{-1}
c'	specific heat of greasy wool expressed on dry weight of clean wool	cal g^{-1} °C^{-1}
q	heat of absorption of water vapour by wool	cal g^{-1}

k	thermal conductivity of bulk greasy wool	cal sec^{-1} cm^{-1} $°C^{-1}$
σ	rate of increase of M with C at constant T $(= dM/dC)$ (see equation 10)	cm^3 g^{-1}
ω	rate of decrease of M with T at constant C $(= dM/dT)$ (see equation 10)	$°C^{-1}$
λ	defined as $= \dfrac{\gamma\omega}{1 + \gamma\sigma}$	g $°C^{-1}$ cm^{-3}
ν	defined as $= \dfrac{q\sigma}{c' + q\omega}$	cm^3 °C g^{-1}
D''	thermal diffusion coefficient $(= k/\rho c)$	cm^2 sec^{-1}
D	"constant vapour concentration" (cf. Henry, 1939) thermal diffusion coefficient $\left(= \dfrac{D''}{1 + q\omega/c'} \right)$	cm^2 sec^{-1}
D''	diffusion coefficient for water vapour through bulk greasy wool	cm^2 sec^{-1}
D	"internal isothermal" (cf. Henry, 1939) diffusion coefficient for water vapour $\left(= \dfrac{D''}{1 + \gamma\sigma} \right)$	cm^2 sec^{-1}
D_1	diffusion coefficient for slow diffusion wave (f_1 or F_1)	cm^2 sec^{-1}
D_2	diffusion coefficient for fast diffusion wave (f_2 or F_2)	cm^2 sec^{-1}

INTRODUCTION

It is commonly considered in the wool trade that diffusion of heat is slow in baled wool (e.g., Cassie, 1957; King, 1959). Not only does wool have a low thermal conductivity, but it also contains a large moisture content when in equilibrium with atmospheres of normal humidities. Thus if an attempt is made to alter the temperature of bulk wool by changing the temperature of the surrounding air whilst the absolute humidity is held constant, then evaporation or condensation of equilibrium moisture will absorb or release latent heat in a manner to oppose the temperature change. One problem of this type recognised commercially is the difficulty of re-warming bales of greasy wool that have become chilled through long continued storage at winter temperatures, since cold greasy wool is difficult to handle when the bale is opened (King, 1959). Consideration of this problem has led to attempts to heat baled wool by radio-frequency energy (Cassie, 1957). Temperature changes in baled wool are important for other reasons. Some bales of pie wool are prone to spontaneous ignition (Walker and Williamson, 1957) and rises in ambient temperature may

or may not heat such bales to a point where the chemical oxidation reactions can liberate sufficient heat to cause a slow thermal explosion (Frank-Kamenetskiĭ, 1939; Walker, 1961). Moreover, some bales of wool are packed during warm weather, and later their temperatures are measured during cold weather. If it is possible for wool bales to resist temperature changes over extended periods of time, this could lead to suspicions of self-heating in bales that are inert.

It has long been known that when a mass of hygroscopic textile fibre such as wool is subjected to a sudden change in surface temperature, diffusion of heat will take place by a mechanism involving the simultaneous diffusion of heat and of moisture. Henry (1939, 1948) developed a mathematical theory showing that such diffusion takes place in two separate waves, one fast and one slow, each involving changes both in temperature and in the concentration of water vapour in the air spaces between the textile fibres. He showed that both these waves can be described by functions which satisfy conventional diffusion theory. Cassie and Baxter (1940) carried out experiments in which moist air was forced through textiles, and Daniels (1941) showed that the results of their experiments agree well with theory (Cassie, 1940). However, Cassie and Baxter (1940) also describe another experiment in which moist air was allowed to diffuse into cotton, and their application of Henry's theory (1939) to the results of this experiment does not show such good agreement. It is uncertain what degree of agreement it would be reasonable to expect, since the mathematical theory requires many simplifying assumptions. In addition to these assumptions, Henry (1939) based his mathematical treatment on two constants σ and ω, and he later (Henry, 1948) demonstrated that in the case of cotton these two "constants" can vary considerably in value. For instance, even in the approximately linear region of the regain curve (say 30% to 60% RH), σ can double in value for a temperature change of as little as 12°C, and ω can double in value for a humidity change of as little as 10% RH (Henry, 1948). It could be expected that similar variations of σ and ω might also occur in the case of wool.

Henry (1939) stated that his equations would apply only to small steps in temperature, but commercial interest is often in larger steps, say 10° to 20°C. In view of doubts over the results to be obtained by direct application of Henry's theory (1939, 1948), or the use of it to make predictions from the results of small-scale trials, it was decided to investigate the diffusion of heat in baled wool by direct experiment with full-sized bales. Because of interest in the practical aspects of the phenomenon, raw wool was used rather than scoured.

Theoretical Considerations

Henry's equations for the coupled diffusion of heat and of moisture have been expressed in several different forms (Henry, 1939; Cassie and Baxter, 1940; Crank, 1956) depending on the purpose for which they are to be applied. Some of these forms lead to unnecessary arithmetical complication in computing, and some (Cassie and Baxter, 1940) contain

errors. All these forms can be inter-converted by the use of equations (4), (5) and (6) below. These are derived from Henry's (1939) basic equation relating the various diffusion coefficients,

$$(1/D_1 - 1/D)\,(1/D_1 - 1/\boldsymbol{D}) = \lambda\nu/D\boldsymbol{D} = (1/D_2 - 1/D)\,(1/D_2 - 1/\boldsymbol{D}) \quad \ldots\ldots(1)$$

As Henry (1939, 1948) has shown, the values of the two diffusion coefficients D_1 and D_2 are given by the solutions of the quadratic equation derived from (1),

$$D_1 = \frac{2\boldsymbol{D}D}{\boldsymbol{D} + D + \sqrt{(\boldsymbol{D} - D)^2 + 4\lambda\nu\boldsymbol{D}D}} \quad \ldots\ldots(2)$$

$$D_2 = \frac{2\boldsymbol{D}D}{\boldsymbol{D} + D - \sqrt{(\boldsymbol{D} - D)^2 + 4\lambda\nu\boldsymbol{D}D}} \quad \ldots\ldots(3)$$

From (2) and (3) we find (cf. Henry, 1939),

$$1/D_1 + 1/D_2 = 1/D + 1/\boldsymbol{D} \quad \ldots\ldots(4)$$

Appropriate substitution of (4) in (1) yields two equations (cf. Henry, 1939),

$$\boldsymbol{D}\,(D/D_1 - 1) = D\,(1 - \boldsymbol{D}/D_2) \quad \ldots\ldots(5)$$

$$D\,(\boldsymbol{D}/D_1 - 1) = \boldsymbol{D}\,(1 - D/D_2) \quad \ldots\ldots(6)$$

In the present work, interest is in changes of temperature caused by sudden changes in the water vapour concentration and/or temperature of the ambient atmosphere. By use of equations (4), (5), and (6) the various forms of Henry's equations can be converted to the forms most suitable for the present purpose, which are,

$$\triangle T = \frac{(\boldsymbol{D}/D_1 - 1)\,\triangle_o T + \nu\triangle_o C}{\boldsymbol{D}/D_1 - \boldsymbol{D}/D_2} f_2 + \frac{(1 - \boldsymbol{D}/D_2)\,\triangle_o T - \nu\triangle_o C}{\boldsymbol{D}/D_1 - \boldsymbol{D}/D_2} f_1 \quad \ldots\ldots(7)$$

$$\triangle C = \frac{(D/D_1 - 1)\,\triangle_o C + \lambda\triangle_o T}{D/D_1 - D/D_2} f_2 + \frac{(1 - D/D_2)\,\triangle_o C - \lambda\triangle_o T}{D/D_1 - D/D_2} f_1 \quad \ldots\ldots(8)$$

As explained by Henry (1939) f_2 and f_1 are solutions to the conventional diffusion equation (i.e., Fick's Law) for the relevant coordinates of position and time, with diffusion coefficients D_2 and D_1 respectively. Since f_2 represents the faster diffusion wave (i.e., $D_2 > D_1$) it has been placed first. Henry (1948) presents a nomogram for solution of D_2 and D_1. However, since calculation of the f_2 temperature wave in wool requires accurate establishment of D_2 it is preferable (and quite simple) to solve (3) and (2) arithmetically.

Some of the present experiments are concerned with a study of the temperature changes resulting in the special case where $\triangle_0 T$ and $\triangle_0 C$ are so proportioned that there is no change in the total moisture content of the textile package in the new atmosphere. In such a case it can be shown that the diffusion of heat will take place almost entirely by the fast f_2 wave, but will be accomplished by a simultaneous diffusion of heat and of water vapour. The change in water vapour concentration will cause the regain to alter slightly, and this will alter temperature in proportion to the ratio q/c'. If these variations in temperature do not have a great influence on the equilibrium regain (at constant concentration of water vapour), the rate of diffusion of heat will be enhanced by this simultaneous diffusion of water vapour. The accelerated diffusion of heat thus depends on a high value of q/c' and a high value of ω. For this postulated case of $\triangle_0 C$ and $\triangle_0 T$ so proportioned as to keep the regain invariant, we can write,

$$\triangle_0 C = dC/dT \; \triangle_0 T \qquad \text{.....(9)}$$

From the definitions of the regain constants (Henry, 1939),

$$\triangle M = \sigma \triangle C - \omega \triangle T \qquad \text{.....(10)}$$

Thus from (10), since regain is invariant,

$$dC/dT = \omega/\sigma \qquad \text{.....(11)}$$

Now, as can be seen from Fig. 8 and from the value of γ (about 0·33 in the present experiments), wool at common bulk densities and atmospheric temperatures will have a value for $\gamma\sigma$ of 10^3 or higher. From the definition of λ, we can thus write as a close approximation,

$$\lambda \simeq \omega/\sigma \qquad \text{.....(12)}$$

The error this will introduce in a practical case is negligible, since σ and ω are not normally known* to an accuracy of 0·1%. For this case of

*For example, although Baxter and Cassie (1941) quote a value of ω for wool to three significant figures, Fig. 9 suggests that ω would change by a factor of two for a change in regain of about 0·05.

invariant regain we can substitute in (7) from (9), (11), and (12), and obtain,

$$\triangle T = \frac{\boldsymbol{D}/D_1 - (1 - \lambda\nu)}{\boldsymbol{D}/D_1 - \boldsymbol{D}/D_2} \triangle_0 T \quad f_2 + \frac{(1 - \lambda\nu) - \boldsymbol{D}/D_2}{\boldsymbol{D}/D_1 - \boldsymbol{D}/D_2} \triangle_0 T \quad f_1 \qquad \text{.....(13)}$$

Now Henry (1939, 1948) has shown that when there is strong coupling between diffusion of heat and diffusion of moisture, $\lambda\nu$ tends towards unity. Substituting in (3) (cf. Henry, 1948),

$$\boldsymbol{D}/D_2 \simeq \frac{1 - \lambda\nu}{1 + D/\boldsymbol{D}} \qquad \text{.....(14)}$$

Substitution from (14) in equation (13) shows that for this case of strong coupling and invariant regain, when $\boldsymbol{D} > > D$ the f_2 wave will approach $\triangle_0 T$, and the f_1 wave will approach zero. The f_2 and f_1 waves will still tend towards these values when $\boldsymbol{D} \leqslant D$, since, when the coupling is strong $\boldsymbol{D}/D_1$ is always large compared to $\boldsymbol{D}/D_2$. Thus from (13) and (14),

$$\triangle T \rightarrow \triangle_0 T \quad f_2 \qquad \text{.....(15)}$$

Henry (1939) suggested that (15) represents the wave that would result if there were no coupling between the two diffusion processes; but for this special circumstance of $\triangle_0 T$ and $\triangle_0 C$ so proportioned as to keep equilibrium regain invariant, (15) has been deduced for the case of strong coupling between the two diffusion processes. The two mechanisms are not identical, as can be seen by comparing D_2 (the diffusion coefficient for the f_2 wave) with $\boldsymbol{D''}$ (the diffusion coefficient for heat alone). For the present case of strong coupling, this comparison can be made by substituting from (12) together with the definitions of ν and $\boldsymbol{D}$, in equation (14). Thus,

$$D_2 = \boldsymbol{D''} + \frac{D}{1 - \lambda\nu} \qquad \text{.....(16)}$$

Equation (16) shows that when the coupling is strong, D_2 is always greater than $\boldsymbol{D''}$; and the propagation of temperature change by the f_2 wave is therefore faster than the diffusion of heat that would be expected from normal theory.

The practical difficulty of proportioning $\triangle_0 T$ and $\triangle_0 C$ in an experiment to keep regain invariant, can be overcome to a close approximation for a wool bale by enclosing it in a vapour-proof envelope before subjecting it to a sudden change in ambient temperature. This ensures that the average regain for the whole bale will not vary, although local variations in regain can still occur. A rigorous mathematical treatment of this problem would require a solution for the system defined by a condition of zero moisture flux at the vapour-proof envelope. However,

in the case of wool, the equilibrium water content is sufficiently large to ensure that the atmosphere at the surface of the bale will almost instantly assume a vapour concentration corresponding to the same regain at the new temperature. Because of the moisture distribution between the two phases, there will be little change in regain of the surface wool in any of the present cases. This changed surface vapour concentration will proceed to diffuse into the bale as if it were an externally applied change, being continually renewed by the moisture reservoir in the wool, and by back diffusion. There is thus little error introduced by applying equation (13) to this case of a wool bale in a vapour-proof envelope.

EXPERIMENTAL

The slipe wool used in these experiments was unscoured first-grade cross-bred, and the sheared wool was greasy Merino. All bales were normal commercial New Zealand bales (not dumped), and relevant details are shown in Table 1. Regain analyses were made by drying samples (*c.* 500 g) to constant weight in a hot air oven at 105° to 110°C (B.S.I. 1953), and would therefore be expected to yield figures about ½% lower than the true regain (Barker and Hedges, 1926). The two bales 6A and 6B (Fig. 6) were prepared by drying the wool in a commercial wool-drier ventilated with heated atmospheric air. A certain amount of cooling took place in this wool before subsequent baling, and the figure quoted in Table 1 for the initial concentration of water vapour in bale 6A is therefore an estimate based on temperature and regain. The two bales 5A and 5B were prepared by enclosing wool bales (initially in equilibrium with air at 21·1°C and 70% RH) in four concentric polyethylene bags, and allowing the bales to reach thermal equilibrium in rooms at the stated temperatures. The bales were then put back into a room at 21·1°C as described, with the polyethylene bags removed from bale 5A. The figure quoted in Table 1 for initial water vapour concentration in bale 5A is therefore also an estimate based on regain and temperature. Both these estimates of water vapour concentration were made by means of the Clausius-Clapeyron equation (Glasstone, 1956 see "Discussion").

Controlled temperature rooms (± 0·2°C) were used as thermostats, and a vigorous internal circulation of air was provided. In the case of the rooms at 47° and 38°C, sufficient ventilation exchange with the atmosphere was provided to ensure that the absolute humidity was substantially the same as atmospheric. The room at −11°C was relatively restricted in ventilation exchange with the atmosphere. The room at 21°C was controlled in relative humidity ± 3% RH. The temperature changes were applied by moving bales from one room to another, one bale of each pair being enclosed in a vapour-proof envelope. Various forms of vapour-proof envelope were used, such as a soldered copper box, four concentric polyethylene bags (two inner 0·002 in. thick and two outer 0·005 in. thick), two concentric polyethylene bags, and a single bag 0·002 in. thick. Temperatures were measured at various positions in the bales by 0·032 in. diameter copper-constantan thermocouples. As would be expected, the central temperature changes lagged after all others; but to simplify presentation of results only the central temperatures are quoted here.

TABLE 1—Details of Wool Bales in Figs 1 to 7

Fig.	External Envelope	Description	Previous Conditioning: History	Previous Conditioning: Time (Days)	Approximate Dimensions (cm)	Temperature (°C): Bale	Temperature (°C): Room	Water Vapour Concentration (10^{-6} g cm^{-3}): Bale	Water Vapour Concentration (10^{-6} g cm^{-3}): Room	Initial Gross Weight (10^3 g)	Initial Regain† (%H_2O on Oven-Dry Greasy Wool)	Fat Content (% Ether Extract on Oven-dry Greasy Wool)	Calculated Diffusion Coefficients (10^{-4} cm^2 sec^{-1}): D''	D_2	D_1
1A	none	Greasy Merino	absorption	166	72 x 72 x 110	19·7	38·0	10	12	154·1	11·6	15·5	9·7	13·9	0·43
1B	2 polyethylene	First slipe	absorption	74	72 x 72 x 110	19·7	38·0	—	—	159·1	17·4	4·5	8·9	14·7	0·21
2A	none	First slipe	absorption	72	72 x 72 x 115	23·0	47·3	15	13	173·7	15·4	10·0	9·4	16·1	0·51
2B	4 polyethylene	First slipe	absorption	60	71 x 73 x 110	22·5	47·3	—	—	150·4	15·7	4·3	9·4	18·2	0·32
3A	none	Greasy Merino	absorption	17	72 x 72 x 110	−11·0	21·2	1	9	155·8	12·8	15·5	9·1	10·1	0·10
3B	4 polyethylene	Greasy Merino	absorption	17	71 x 73 x 110	−11·1	21·2	—	—	141·7	12·2	17·0	9·6	10·7	0·11
4A	none	Greasy Merino	as sheared	25	72 x 72 x 110	−10·9	38·3	1	10	159·3	15·3	15·5	9·3	11·0	0·18
4B	1 polyethylene	Greasy Merino	as sheared	18	72 x 72 x 112	−10·7	38·3	—	—	144·6	14·3	21·7	9·6	11·9	0·14
5A	none	First slipe	absorption	9	71 x 73 x 110	47·2	21·1	58*	10	150·1	15·6	4·3	9·4	17·8	0·38
5B	2 polyethylene	First slipe	absorption	9	72 x 72 x 110	45·6	21·1	—	—	158·8	17·1	4·5	8·9	16·4	0·24
6A	none	First slipe	desorption	0	72 x 72 x 115	48·6	21·0	5*	14	155·1	2·7	10·0	9·5	15·5	0·51
6B	copper	First slipe	desorption	0	71 x 72 x 115	46·6	21·0	—	—	151·9	2·4	12·1	10·5	11·5	0·50
7A	none	Greasy Merino	absorption	62	71 x 73 x 110	20·7	−11·1	11	1	141·1	11·7	17·0	9·6	10·8	0·11
7B	4 polyethylene	Greasy Merino	absorption	62	72 x 72 x 110	20·6	−11·1	—	—	155·7	12·8	15·5	8·9	10·0	0·09

NOTE: †See B.S. 1051 : 1953. *Indicates estimated figure. —Indicates not determined.

RESULTS

The central bale temperatures resulting from the external temperature and atmosphere changes detailed in Table 1 are shown plotted in Figs 1 to 7. The relevant experimental details are shown in Table 1. Each figure comprises a pair of bales with one bale enclosed in a vapour-proof envelope. Although the two sets of plotted points are shown on the same graph to facilitate comparison, the two experiments were not always carried out at the same time. Thus there are sometimes differences in the initial temperatures (see Table 1).

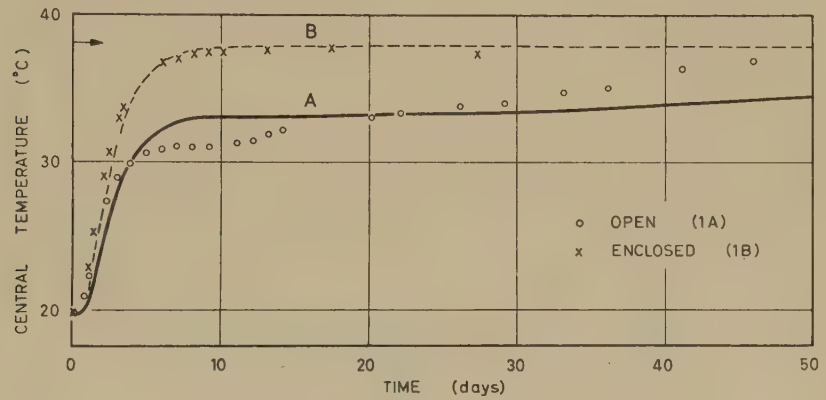

FIG. 1—Temperature changes in wool bales 1A and 1B.

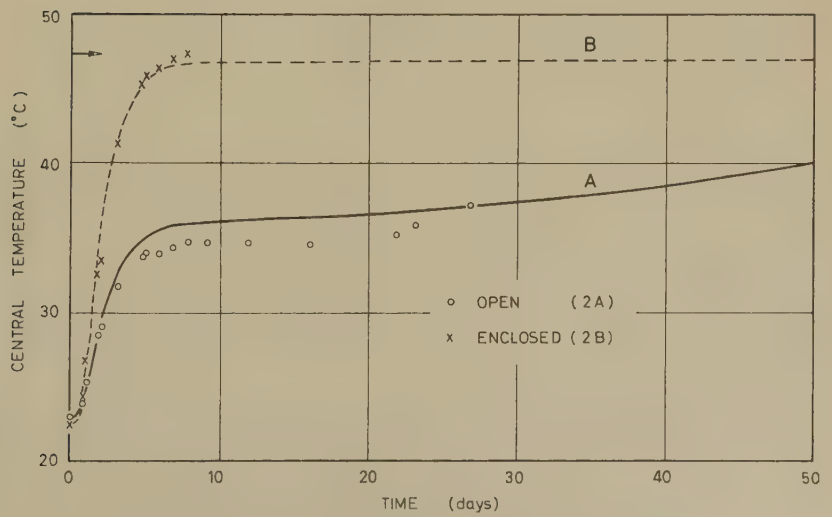

FIG. 2—Temperature changes in wool bales 2A and 2B.

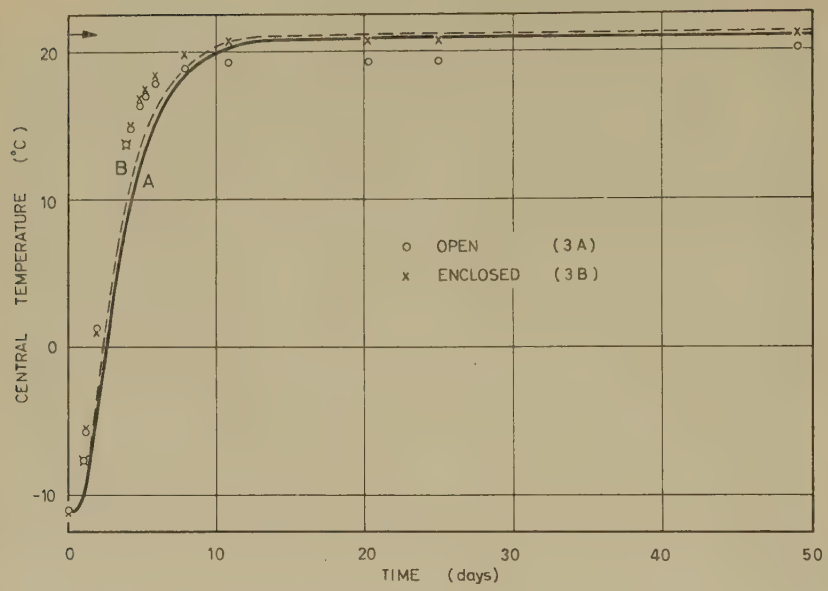

FIG. 3—Temperature changes in wool bales 3A and 3B.

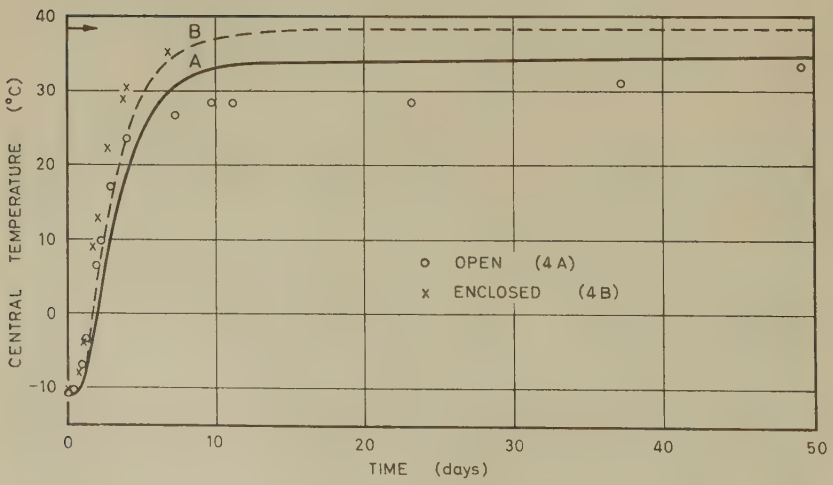

FIG. 4—Temperature changes in wool bales 4A and 4B.

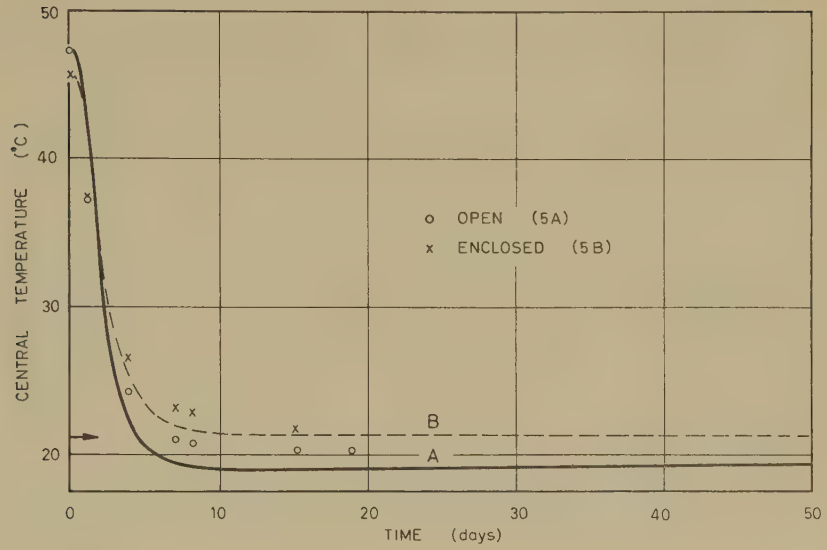

FIG. 5—Temperature changes in wool bales 5A and 5B.

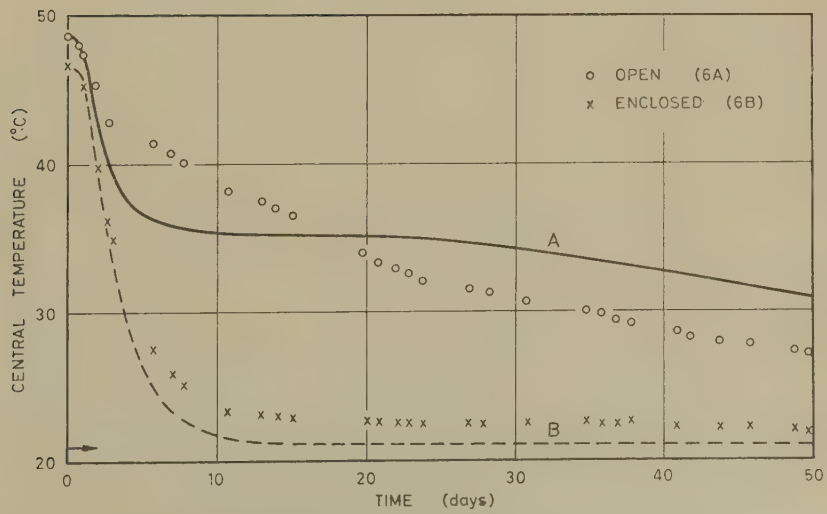

FIG. 6—Temperature changes in wool bales 6A and 6B.

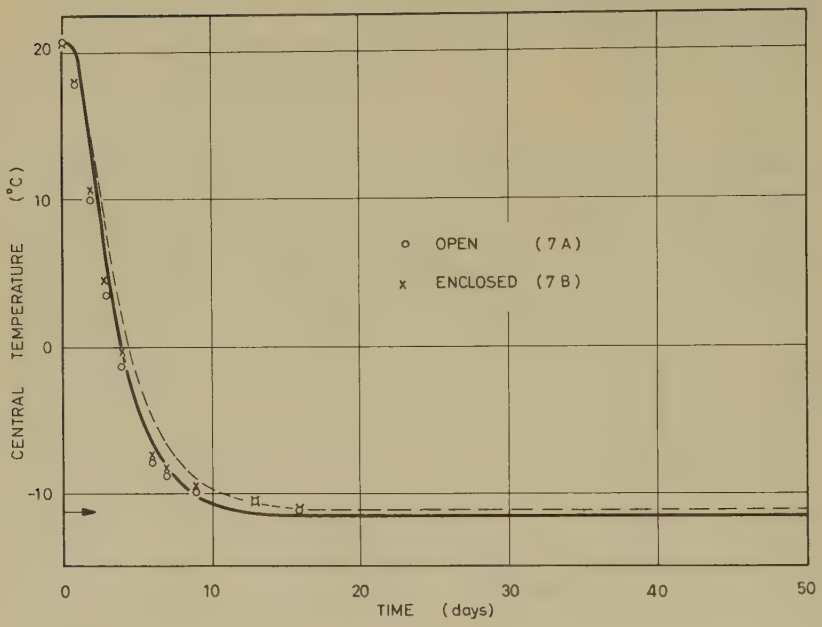

FIG. 7—Temperature changes in wool bales 7A and 7B.

DISCUSSION

Parameters Required

σ and ω. Although values of these two parameters have been calculated for wool in the range 17° to 31°C and 33% to 75% RH (Cassie, 1940; Cassie and Baxter, 1940; Baxter and Cassie, 1941) it was considered likely that values would vary in a manner similar to that demonstrated for cotton (Henry, 1948). A complete regain curve for clean wool at 25°C has been established by Speakman (1930), and these figures have been smoothed and summarised (W.I.R.A., 1955, p. 9). The averages of absorption and desorption values of relative humidity on this curve were accordingly converted (at each value of regain) to other temperatures by means of the Clausius-Clapeyron equation (Glassstone, 1956 – see also Shorter, 1924). The values employed for the heat of reaction between wool and liquid water were based on the experimental data summarised by W.I.R.A. (1955, p. 18); and the simplifying assumption was made that these values would not vary with temperature. For convenience, the definition of relative humidity chosen was a ratio of water vapour concentration in the air to the concentration at saturation (B.S.I., 1953). In this way values of σ and ω were computed, and are shown in Figs. 8 and 9. Since the regain figures quoted by Speakman (1930) were determined by chemical drying,

the values of regain determined (B.S.I., 1953) in the present work were increased (Barker and Hedges, 1926) by 0·5% (on the clean dry weight) before reading values from Figs 8 and 9.

γ. The published figures for densities of clean wool fibres at various regains have been summarised (W.I.R.A., 1955, p. 206). As an approximation, the grease was assumed to have a density of 0·95 g cm^{-3}, and to occupy space independently of the wool fibre.

k. The thermal conductivity values used were based on those calculated (Walker and Harrison, 1960a) from Schuhmeister's equation (1877). Since these calculated figures relate to completely dry wool, allowance was made for the presence of regain moisture in wool of the present densities by increasing the values of thermal conductivity by 0·55% for each 1% of regain (cf. Baxter, 1946b). Figures based on this symmetrical form of Schuhmeister's equation (1877) assume the packing to be isotropic, although wool in the present press-packed bales would not be completely isotropic.

c and c'. Specific heats were computed by direct addition of the specific heats of wool (Matthews, 1927), water, and grease (assumed 0·4 cal g^{-1} $°C^{-1}$) although it is probable that these parameters are not strictly additive (cf. Shipley *et al.*, 1939).

q. To the latent heat of vaporisation of water at the relevant temperature, was added the heat of reaction between wool and liquid water (W.I.R.A., 1955, p. 18).

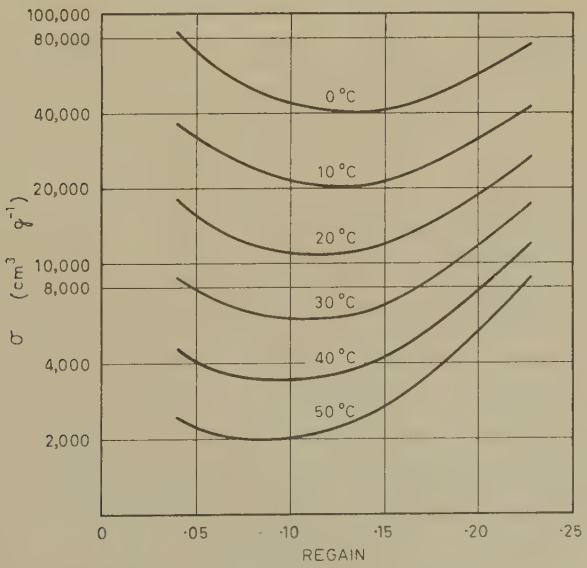

FIG. 8—Values of σ for wool.

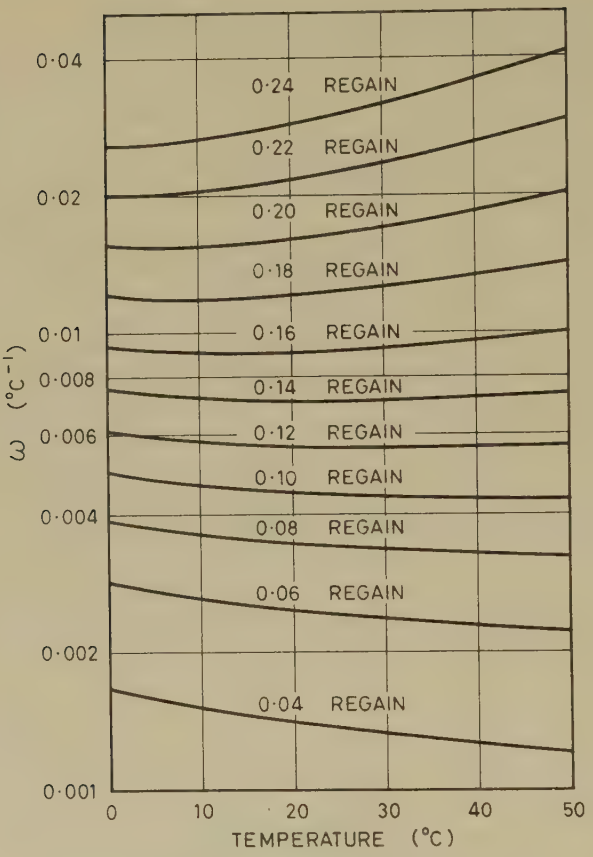

FIG. 9—Values of ω for wool.

D″ Although the diffusion coefficient of water vapour in free air is known (Boynton and Brattain, 1929), there is considerable doubt over its value in wool. Henry (1939, 1948) reports a sixfold variation in experiments designed to measure *D″* in bulk cotton. Baxter (1946a) has measured the diffusion coefficient of water vapour through thin layers of proofed wool fabrics, and has shown that his results are consistent with an equation of the form suggested by Schuhmeister (1877) when due allowance is made for the anisotropic state of the woven fabric. In view of the scatter of Baxter's experimental figures (1946a), and for lack of better data, values for *D″* half those in free air have been assumed in the present case of wool at densities of about 0·27 g cm^{-3}, and at all values of regain. Figures of this magnitude would be consistent with the experimental data reported for wool by Baxter (1946a); and also with the experimental data reported for cotton by Pierce *et al.* (1945). Lincoln (unpublished – via W.I.R.A., 1955, p. 59) has shown that the diffusion

coefficient for water vapour measured under steady-state conditions in felted wool (at unspecified density and temperature) can double for a change in regain of 10%. However, for lack of more detailed knowledge of these effects, no attempt was made in the present work to correct D'' for variations in regain.

f_1 and f_2. Temperatures to be expected at the centres of each bale at various times were calculated for the two diffusion waves, using the functions tabulated by Olson and Schultz (1942). The dimensions of all bales were assumed to be 72 × 72 × 110 cm (a close approximation – see Table 1), and diffusion parameters computed for parallelepipeds of these dimensions are shown in Table 2 (c.g.s. units).

TABLE 2—Thermal Diffusion into a Parallelepiped 72 × 72 × 110 cm.

Function f Central Temperature Change (%)	Product of Diffusion Coefficient and Elapsed Time (cm^2)
10	129
20	171
30	209
40	250
50	294
60	346
70	412
80	502
90	654

Interpretation of Experiments

Because Henry's equations (1939) involve small differences between large quantities, it is essential to use consistent values of the various parameters. For instance, as shown in Fig. 8, a change of 30°C can cause a six-fold variation in the value of σ. Since the present experiments involve temperature changes of this order, it was therefore decided to make calculations for each experiment based on a temperature midway between the initial and final temperatures, and a value of regain midway between the initial and final regains (corrected to a basis of completely dry grease-free wool). Since none of these experiments were continued to a point where the bale reached regain equilibrium with the final atmosphere, estimates of final regain for those bales not enclosed in a vapour-proof envelope (bales 1A to 6A) were made from the measured values of ambient temperature and relative humidity by means of the Clausius-Clapeyron equation (Glasstone, 1956 – see above). In the case of bale 7A the value of water vapour concentration at −11·1°C (Table 1) was inadequate to establish an ultimate regain for the wool, so a value of regain was used intermediate between the initial and final average regains. Midway values of regain for those bales enclosed in vapour-proof envelopes were calculated from averages of bale weights before and after each experiment.

These values of mid-temperature and mid-regain were assumed as averages for each bale, and values of σ and ω were read from Figs 8 and 9. Simi-

larly, values of ρ, γ, k, c, c', q. and D'' were calculated as described above, for these same values of temperature and regain. From these figures, other required parameters were calculated from the definitions given under "Symbols and Units". In this way equations (7) and (13) were applied to the various experiments (i.e., respectively to the bales exposed to room atmosphere, and to the bales enclosed in a vapour-proof envelope), and the predicted variations of central temperature were computed from the data of equations (2) and (3) and Table 2. These curves are shown in Figs 1 to 7, drawn solid in the case of bales exposed to room atmosphere (1A to 7A), and dotted for bales enclosed in a vapour-proof envelope (1B to 7B). The relevant calculated diffusion coefficients are shown in Table 1.

In the case of bales exposed to room atmosphere, it could be argued that unless changes in weight are small, it is illogical to use median values of temperature and of regain. Not only are the distributions both of temperature and of regain moisture non-uniform throughout the bale at these particular stages in each experiment, but the two conditions do not occur simultaneously. Thus Henry (1939, 1948) has shown that the regain change (i.e., weight change) takes place almost wholly by the slow f_1 wave, whilst a large portion of the temperature change takes place by the fast f_2 wave. Because of this, in many cases the weight will have changed very little when either the "mean" temperature or the central temperature has reached the midway point. Similarly, because a large portion of the temperature change commonly takes place by the f_2 wave, a pseudo-equilibrium value of temperature is rapidly reached throughout the bale, and all propagation of the f_1 wave then takes place at temperatures between this pseudo-equilibrium and the final temperature. This can influence the values of the diffusion coefficients D and D_1. However, further calculations have been made in regard to the present experiments 1A to 7A, using alternative parameter values. These values were based on conditions obtaining at the time when temperature at the centre of each bale had reached a value midway between the initial and final values. At this time an average regain was calculated from the then weight of the bale, and this regain was assumed as an average for the bale. Values of σ, ω, ρ, γ, k, c, c', q, and D'' were determined as before for wool of this regain (corrected to a basis of completely dry grease-free wool), and at the midway temperature. When values of central temperature are predicted in this way by application of equation (7) and Table 2, they do not differ markedly from the calculated values shown in Figs 1A to 7A. (For example, a difference of about 5% of $\triangle_0 T$ in the value of pseudo-equilibrium). It is thus seen that the present technique of using median values of both temperature and regain is a reasonable compromise, and offers the advantage of being also applicable to calculation of changes in regain (see Part 2), where the f_2 wave is normally small (Henry, 1948). It also offers the advantage of ensuring that the same values of the various parameters would be applied to calculations of experiments in which the atmosphere changes are reversed (e.g., 3A and 7A).

As can be seen from Figs 1 to 7, equations (7) and (13) are successful over a wide range of conditions in predicting the general form of temperature change to be expected. There is good agreement between theory

and experiment regarding the relative amplitudes of the f_2 and f_1 waves, and agreement is rather less over the magnitudes of the two diffusion coefficients, D_2 and D_1. In almost every case the f_2 wave took place a little faster than predicted by theory; and in every case where experimental observations were made of the f_1 wave, this also took place considerably faster than predicted by theory. In all the present experiments the calculations yield a value of $\lambda\nu$ close to unity, indicating a close coupling between diffusion of heat and diffusion of moisture. It is therefore interesting to apply the simplified equation (16) to the present experiments. In every case it is found that (16) yields a diffusion coefficient for the f_2 wave which provides equal (or slightly better) agreement with the experimental results than does the more rigorous equation (3).

In the present experiments, the f_1 wave is of significant amplitude only in Figs 1A, 2A, 4A, and 6A. As the diagrams show, in three of these cases the observed velocity of the f_1 wave is considerably faster than would be expected from application of the diffusion coefficient D_1 (calculated from equation (2) using parameters at mid-temperature and mid-regain) to the functions given in Table 2. It is interesting to compare these results with the results of the diffusion experiment with cotton reported by Cassie and Baxter (1940). They found that the f_1 wave in their case was considerably slower than that calculated from Henry's theory (1939), and suggested that this was due to the high density of the linen sleeve enclosing their sample of cotton. Cassie (1948) later suggested that the discrepancy would more probably be due to employment of the diffusion coefficient for water vapour in free air, as the value of D''. The experimental results in Figs 1, 4, and 6 demonstrate that the observed f_1 wave in wool for these three cases is much more rapid than the f_1 wave predicted by using constants based on a temperature and a regain midway between the initial and final values. The calculated velocity of the f_1 wave will depend on the value assumed for the diffusion coefficient of water vapour in wool (D''), and Cassie (1948) has suggested that more complex diffusion coefficients should be used than the present assumption of half the value in free air. However, the present values are consistent with experimentally measured diffusion coefficients in wool (Baxter, 1946a) and in cotton (Pierce *et al.*, 1945). They probably represent a closer approach to the real values (for wool) than does Henry's suggestion (1948) of using a value of D'' for cotton independent of packing density between 0·2 and 0·5 g cm^{-3}. The experiment described by W.I.R.A. (1955, p. 59) suggests that if allowance were made for the influence of regain moisture, this would have little effect on the present calculations, except perhaps for bales 6A and 6B.

Some bales of pie wool are known to react exothermally with atmospheric oxygen (Walker and Williamson, 1957), and the present experiments permit assessment of the part that changes in ambient temperature might play in raising the internal temperature of such bales to a point where spontaneous ignition is possible. The parameters and relationships discussed by Walker (1961) suggest that a parallelepiped of pie wool of the present dimensions and density (i.e., an "undumped" bale of commercial size) would cause a slow thermal explosion if the rate of heat generation at the temperature of the surface approached about 10^{-5} cal sec^{-1} g^{-1}. Walker

(1961) has also calculated that raising the surface temperature of a spherical bale of dry pie wool by only 20°C could (under certain conditions) change it from a relatively non-reacting thermally stable condition, to a state of thermal instability, thus leading to spontaneous ignition. This would occur if the pie wool were sufficiently reactive, and if the rise in ambient temperature were able to influence the internal temperature of the bale sufficiently rapidly to initiate a thermal explosion before the ambient temperature was changed back to its original level. For instance, if the ambient temperature of a bale of wool were suddenly raised, any internal liberation of heat due to chemical reaction would initially be adiabatic. If a mean internal rate of generation of heat is assumed of $0{\cdot}5 \times 10^{-5}$ cal sec^{-1} g^{-1}, and a specific heat of greasy wool (at normal regain) of say 0·4 cal g^{-1} $°C^{-1}$, then the chemical reaction would take over 18 days under adiabatic conditions to raise the internal temperature of such a bale by 20°C. However, the present experiments show (cf. Fig. 1A) that a rise in ambient temperature from 20° to 38°C could raise the central temperature of a bale of inert greasy wool by 10°C in 3½ days, purely by coupled diffusion of heat and moisture. If the relative humidity of the ambient atmosphere were maintained approximately constant, the rise would be even more rapid. (cf. Fig. 1B). This temperature rise would increase the rate of chemical reaction throughout the bale, and diffusion of heat in this manner would therefore greatly shorten the time needed for the central bale temperature to rise to a dangerous level. When bales of apparently inert pie wool are carried through the tropics by ship, they are normally subjected to a temporary rise in ambient temperature accompanied by a rise in the concentration of water vapour in the ambient atmosphere. The present experiments show that this brief rise in ambient temperature could diffuse into the wool bales in a few days, and must therefore be considered as creating a much greater spontaneous ignition hazard than would occur if baled wool were resistant to such a diffusion of heat.

Since certain grades of wool are known to ignite spontaneously (Walker and Williamson, 1957), many bales of various grades of wool are tested in commerce in New Zealand to see if the internal temperature is higher than atmospheric. This testing can be carried out by insertion of a spear thermometer or a thermocouple, but it is more commonly carried out in commerce by insertion of a sharpened steel "spike" about 18 in. long and $\frac{5}{16}$ in. diameter, which is later withdrawn and its temperature estimated by touch. In the hands of an alert operator this is a very sensitive and reliable test. When bales are discovered to be warmer than atmospheric temperatures, doubt can exist whether the heat is due to incipient spontaneous ignition (Walker and Williamson, 1957) to fungal metabolism in damp wool (Walker and Harrison, 1960b), or to retention in the bale of stored heat. Both Henry's theory (1939) and the present results show that if the relative humidity of the ambient atmosphere is initially in approximate equilibrium with the wool, and is not greatly altered when the atmospheric temperature changes, then variations in mean atmospheric temperature will propagate into undumped wool bales within 3 or 4 days. Further experiments (unpublished), and also application of Henry's theory (1939), show that dumping (i.e., compression to conserve shipping space) will not greatly alter this delay time – particularly in the case of "single-dumping". Inert

wool can remain hotter than its environment over many days only if it has been packed in an over-dried state (e.g. Fig. 6A). Therefore, if the interior of a wool bale is found to be consistently hotter than its environment over the course of several days, and if it does not contain an excessively high or an excessively low moisture content, this temperature rise can be taken as evidence of incipient spontaneous ignition.

In the case of the bales enclosed in vapour-proof envelopes, the rates of thermal diffusion actually observed may be compared with those predicted by direct application of D'' (see Table 1), the conventionally calculated coefficient of thermal diffusion in an inert material. In each case D'' was smaller than D_2 (Table 1), and application of D'' to the data of Table 2 yields values of central temperature changing more slowly with time than the observed values shown in Figs 1B to 7B. This demonstrates the validity of applying equation (13) to these bales, and shows that the approximation represented by equation (15) holds for this case of invariant regain with strong coupling between diffusion of heat and of moisture, as well as for Henry's suggested (1939) case of weak coupling. The use of a vapour-proof barrier around a bale therefore offers a method of suppressing the f_1 wave, and thus accelerating the propagation of temperature change through the consequently increased amplitude of the f_2 wave.

The present experiments show that wool bales containing normal regain moisture that have become "frozen", can be warmed back to normal temperatures by exposure to air of normal temperature and humidity (say 20°C and 60% RH) for three or four days. Even if air of an appreciably lower relative humidity is used, the propagation of temperature change still takes place mainly by the f_2 wave, and the major part of the temperature change is therefore rapid. Because of this, the warming-up process can be accelerated if hotter air is used (at the same absolute humidity), as can be seen by comparison of Figs 3 and 4, or by the application of equation (7). If delays of two or three days can be tolerated, it is thus unnecessary to use expensive techniques such as radio frequency heating to "thaw" wool bales, or to use live steam as suggested by Cassie (1957), and by King (1959). By enclosing each bale in a polyethylene bag 0·002 in. thick, 50% of the applied temperature change can be made to take place in two days, and 80% in four days. The experiment described by Cassie (1957) employed a wool bale of about the same weight as those used in the present experiments. The reported failure to observe a central temperature change greater than one degree after sixteen hours at 140°F, is consistent with the present experimental results.

The bales enclosed in vapour-proof envelopes were weighed before and after each experiment, and the greatest difference found was 800g. (In the temperature ranges employed, buoyancy corrections would be less than 100g). Some of these observed weight changes are considered to have taken place during unavoidable delays in weighing after removal of the vapour-proof envelopes. For example, the bale 6B was found to have gained 400 g, although the soldered copper box would undoubtedly be an effective vapour barrier. However, the experiments demonstrated that the polyethylene bags were sufficiently impermeable to water vapour to reduce weight changes to a level unimportant commercially, and this was true even when

a single film 0·002 in. thick was used as a barrier (Fig. 4B and similar unreported experiments). The low cost of such a bag would make its use commercially feasible for accelerating the diffusion of heat into wool bales, even if damage limited its re-use. To discover how long bales heated in this manner might retain the increase of temperature, bale 4A was removed after 80 days in the room at 38·3°C, by which time it had reached a central temperature of 37·3°C. Similarly bale 4B was removed after $6\frac{3}{4}$ days in the room at 38·3°C, by which time it had reached a central temperature of 35·1°C. Immediately after removal, both bales were placed in a room at 20·6°C and 52% relative humidity, with the polyethylene bags removed from bale 4B. The central temperatures subsequently measured in these bales are shown in Fig. 10. It will be noticed that bale 4B shows an f_1 wave in opposition to the f_2 wave (Fig. 10), since the

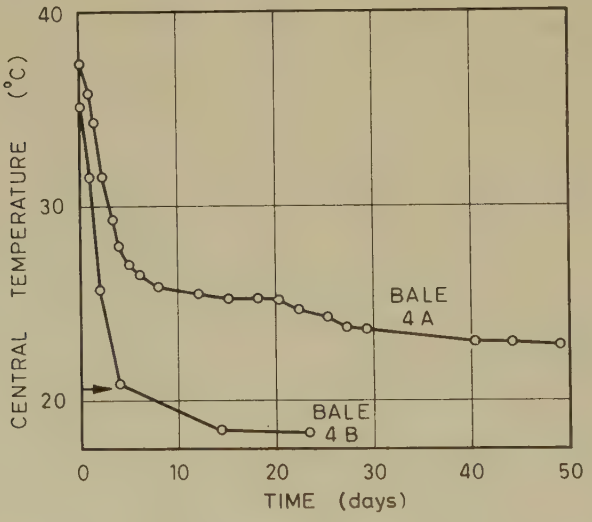

FIG. 10—Subsequent cooling of bales 4A and 4B.

regain moisture it contained would represent equilibrium with a relative humidity higher than 52% (Table 1). As might be expected, bale 4A shows a pronounced f_1 wave (Fig. 10) caused by the evaporation of moisture that had taken place during 80 days at 38·3°C and 22% RH.

In the experiments with "frozen" wool bales, it is interesting to note that Figs 3, 4, and 7 show no evidence of a phase change in the regain moisture at temperatures down to −11°C. This parallels the observations of Shipley *et al.* (1939) of the regain moisture in cotton down to −35°C, and is in conflict with the views of Whitwell and Toner (1946).

CONCLUSIONS

1. Henry's two constants σ and ω will vary according to the values of regain and temperature, in the case of wool.

2. The propagation of a sudden external temperature change into baled wool is more rapid than has been generally considered in the wool trade, and can be accelerated by enclosing the bale in a polyethylene envelope.

3. Over the range of temperature change of 20° to 50°C, the proportion of the total temperature change propagated by the fast diffusion wave will vary according to the atmospheric conditions, and can be predicted by Henry's theory of coupled diffusion.

4. The observed velocity of the fast temperature wave in baled wool is in accord with Henry's theory. However, in the few cases where observations were made and where the f_1 wave was of appreciable amplitude, the velocity of the slow temperature wave was found to be considerably faster than that predicted by Henry's theory.

5. When bales of potentially reactive pie wool are transported through the tropics, sufficient heat could diffuse into the bales in a few days to increase the spontaneous ignition hazard.

6. If bales of wool are found to be consistently hotter than their environment over several days, and if the moisture content is not excessively low or excessively high, this can be taken as evidence of incipient spontaneous ignition.

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Part 2. CHANGES IN BALE WEIGHT

Summary

The experiments described in Part 1 are discussed in relation to the variations observed in total bale weight, and the variations predicted by a modified form of Henry's equation. A calculation is made of the likely variations in regain of wool in conditioning bins.

INTRODUCTION

All natural textile fibres have a definite moisture content, when in equilibrium with an atmosphere of given temperature and relative humidity (if effects of hysteresis are disregarded); and the equilibrium moisture content of wool is highest of all. When bales of wool are moved from

one location to another in commerce, the variations in ambient atmosphere can cause changes in the weights of the bales, with consequent possibilities of confusion. To overcome this difficulty, textile fibres are often sold on the basis of an equivalent dry weight modified to a corrected invoice weight by an accepted "official regain". Suggested standards of official regain are quoted in B.S.I., 1953, together with a method of determining the correct invoice weight by analysis of moisture content. In commerce involving baled wool it is obviously impracticable to carry out this procedure whenever bale weights are checked, and it is therefore desirable both to keep weight changes to a minimum, and to know how rapidly bale weights are likely to change under given conditions. Since the heat of wetting of wool is high, equilibration of the moisture in baled wool with the water vapour in an ambient atmosphere will take place by a simultaneous diffusion of water vapour and of heat. Henry (1939, 1948) has proposed a theory showing how these two processes will be coupled together in a manner depending on the properties of the textile.

Few experiments have been carried out to investigate the rate of weight changes in packages of textile fibres. Crank (1960) describes the results of experiments on small packages of cotton, silk, rayon, and nylon, at a range of densities, temperatures, and regains. Crank (1960) also quotes the results of an experiment with a miniature bale of cotton under unspecified conditions, together with a prediction (by extrapolation) of the rate of regain change that would take place in a full-sized bale (roughly 5 ft $\times$ 2 ft $\times$ 2 ft) of the same material. Balls (1936) has described a series of experiments with cotton bales of commercial size, but his results are mostly concerned with transient waves, and do not establish the rate of weight change that could occur in commerce when bales are initially remote from a state of equilibrium with a relatively stable ambient atmosphere.

Lack of moisture equilibrium between wool bales and an ambient atmosphere can arise in commerce for other reasons besides the transport of bales to a new environment. Edmunds (1961) has investigated the distribution of moisture within selected bales of scoured wool, and describes a case where wool at the centre of a bale was found to have a regain of 10%, rising to 14% near the surface. This was stated to have been caused by the wool being baled whilst still over-dry after scouring and machine drying, a not uncommon practice (e.g., Pressley, 1956). Rothbaum and Vere-Jones (1960) have described a method of rapid moisture analysis that would help avoid such an effect. However, wool can be baled in an over-dry condition under circumstances where it is not expedient to control its moisture content in this way. For example, sheep that have stood in hot sunshine are sometimes sheared in a shed roofed with metal sheets, with a consequent low relative humidity in the ambient atmosphere. When such wool is baled it is unlikely to be in moisture equilibrium with the surrounding atmosphere. For these reasons, it was desired to discover if the rate of attainment of equilibrium regain in wool bales of commercial size could be predicted from a knowledge of the relevant conditions, and without experimental determination of $\triangle_0 M$ since this would not always be possible under commercial conditions.

Theoretical Considerations

Henry (1939) deduced that when a package of textile fibres is subjected to simultaneous sudden changes in the ambient atmosphere of both water vapour concentration and temperature, the consequent changes in regain moisture could be expressed by an equation,

$$\triangle M = \triangle_0 M\, f_1 + \left\{ \frac{1/D_1 - 1/D - q\omega/c'D''}{1/D_1 - 1/D_2} \triangle_0 M \right.$$

$$\left. + \frac{1/D'' - 1D''}{1/D_1 - 1/D_2}\, \omega \triangle_0 T \right\} (f_2 - f_1) \qquad \text{.....(17)}$$

This is not a suitable form of equation to predict changes of weight in baled wool, since it invloves $\triangle_\infty M$, the ultimate change in regain moisture for the sample under consideration. For the purpose of predicting weight changes of bales under commercial conditions, it is possible to deduce a more suitable form of Henry's equation (1939) for change of regain, without involving $\triangle_0 M$. First substituting in (8) from (5) and (6), we obtain,

$$\triangle C = \frac{(1 - \boldsymbol{D}/D_2)\ \triangle_0 C + \boldsymbol{D}/D\ \lambda \triangle_0 T}{\boldsymbol{D}/D_1 - \boldsymbol{D}/D_2} f_2$$

$$+ \frac{(\boldsymbol{D}/D_1 - 1)\ \triangle_0 C - \boldsymbol{D}/D\ \lambda \triangle_0 T}{\boldsymbol{D}/D_1 - \boldsymbol{D}/D_2} f_1 \qquad \text{.....(18)}$$

Then substituting in (10) from (7) and (18), and rearranging,

$$\triangle M = \frac{(1/\boldsymbol{D} - 1/D_2 - \lambda\nu/\boldsymbol{D})\sigma \triangle_0 C + (1/\boldsymbol{D} + 1/D - 1/D_1)\,\omega \triangle_0 T}{1/D_1 - 1/D_2} f_2$$

$$+ \frac{(1/D_1 - 1/\boldsymbol{D} + \lambda\nu/\boldsymbol{D})\sigma \triangle_0 C - (1/\boldsymbol{D} + 1/D - 1/D_2)\omega \triangle_0 T}{1/D_1 - 1/D_2} f_1$$

.....(19)

Now if the definition of ν is multiplied by the approximation represented by (12), we find,

$$\lambda\nu \simeq \frac{q\omega}{c' + q\omega} \qquad \text{.....(20)}$$

Substituting from (4) and (20) together with the definition of D, in equation (19),

$$\triangle M = \frac{(D_2/D'' - 1)\ \sigma\ \triangle_o C + \omega\ \triangle_o T}{D_2/D_1 - 1} f_2 + \frac{(1 - D_1/D'')\ \sigma\ \triangle_o C - \omega\ \triangle_o T}{1 - D_1/D_2} f_1 \quad \text{.....(21)}$$

As before (Part 1), the two diffusion waves f_2 and f_1 can be evaluated by solution of the conventional diffusion equation (Fick's Law) with diffusion coefficients D_2 and D_1 respectively (equations 3 and 2). In many problems of weight changes in baled textiles, interest is centred more on F_2 and F_1, the integrated diffusion functions corresponding to the total weight change of the package, and therefore obtainable by integrating f throughout the package. Values of F for a plane sheet of finite thickness have been presented by Hill (1928) and by Henry (1939), and these figures are here used to calculate integrated diffusion parameters for a parallelepiped 72 × 72 × 110 cm as shown in Table 3.

TABLE 3—Regain Diffusion into a Parallelepiped 72 × 72 × 110 cm.

Function F Average Change in Regain (%)	Product of Diffusion Coefficient and Elapsed Time (cm^2)
10	1·5
20	6·7
30	16·1
40	31·7
50	55·0
60	89·2
70	140
80	218
90	364

EXPERIMENTAL

In the experiments described in Part 1, the weights of those bales freely exposed to room atmosphere (i.e., bales 1A to 7A) were determined at various times during each experiment. Due to restricted availability of weighing facilities, readings were not obtained in all cases as frequently as was desirable.

RESULTS

In Figs 11 to 17 are plotted the variations in gross bale weights resulting from the changes in external temperature and atmosphere for bales 1A to 7A of Table 1 (Part 1).

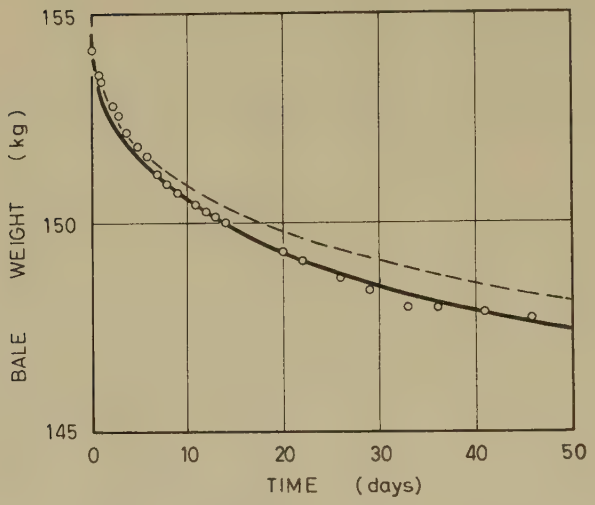

FIG. 11—Weight of bale 1A.

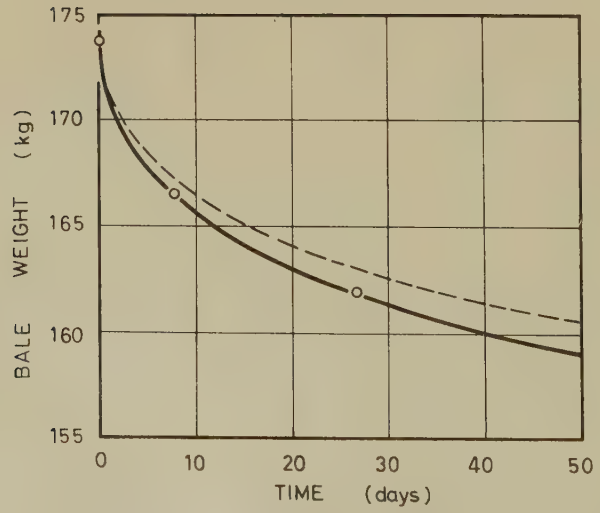

FIG. 12—Weight of bale 2A.

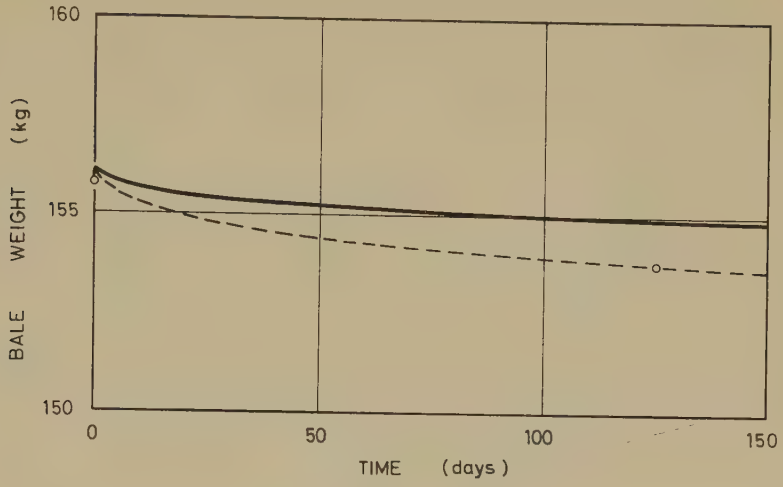

FIG. 13—Weight of bale 3A.

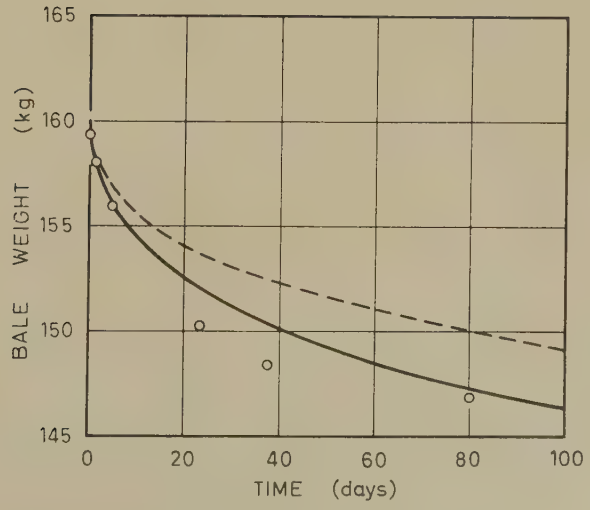

FIG. 14—Weight of bale 4A.

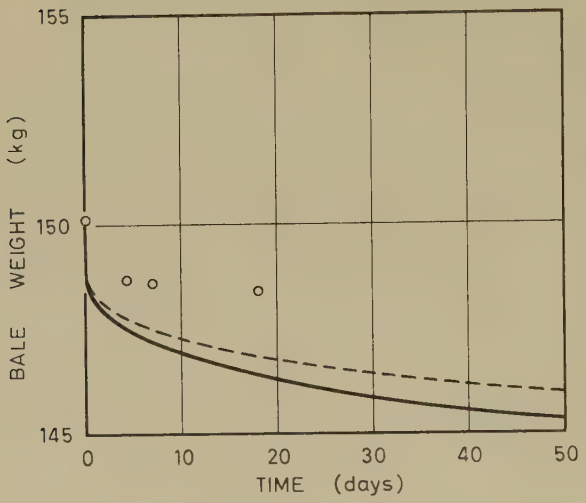

FIG. 15—Weight of bale 5A.

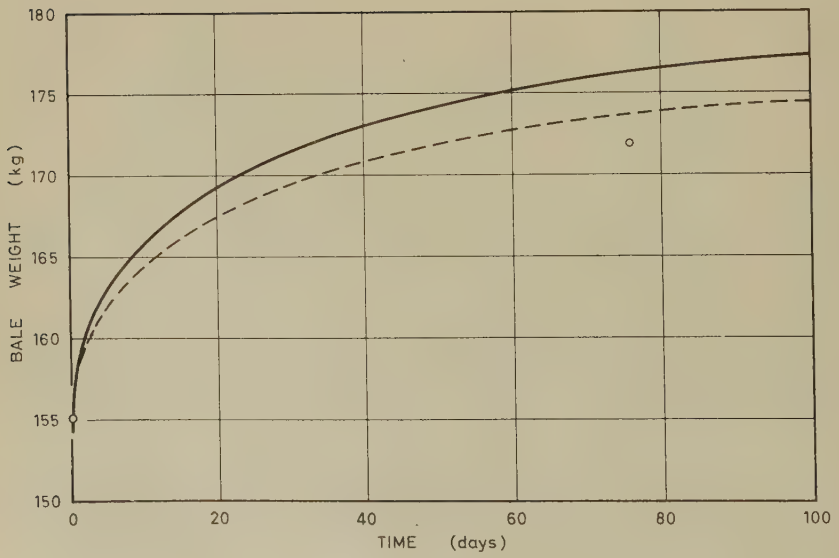

FIG. 16—Weight of bale 6A.

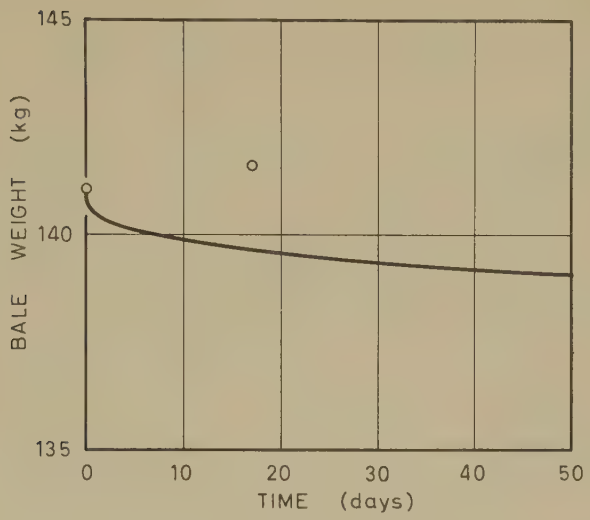

FIG. 17—Weight of bale 7A.

DISCUSSION

The fabric wool packs (some jute, others *Phormium tenax*) used to enclose the bales in these experiments each weighed about 4 kg. However, in the case of each bale, gross weight is quoted rather than net. The reason for this is that the pack fabric bears a closer similarity to wool in its moisture relationships than it does to an inert material. This is relevant in considering the early part of weight change curves, when bales are subjected to a sudden change of environment. It is therefore preferable to consider gross bale weights rather than net, and these are shown in Figs 11 to 17 and are used in all calculations.

Using as before (Part 1) values of temperature and of regain midway between the initial and final values, the values of σ, ω, ρ, γ, c, c', q, and D'' and the parameters of Table 1 were substituted in the definitions of λ and ν and in equations (2), (3) and (21) for each experiment 1A to 7A. The functions of Table 3 were applied to the data of Table 1 and equation (21) to predict variations of gross bale weight in each experiment, at various time intervals. These curves are shown drawn solid in Figs 11 to 17. In many of these experiments the data are insufficient to permit of conclusions being drawn. However, in Figs 11, 12, and 14 there is reasonable agreement between theory and experiment. It should be noted that in each of these cases the F_2 wave is of small amplitude, and acts in opposition to the F_1 wave. An equally good agreement between experimental results and theory might therefore have been provided if the estimated ultimate change in bale weight were smaller and the value of D_1 (the diffusion coefficient for the F_1 wave) rather larger. In Figs 13 and

16 the experimental results are not inconsistent with theory, but insufficient weighings have been made to draw conclusions. In Figs 15 and 17 little relationship is apparent between experiment and theory.

Since the $(f_2 - f_1)$ term in (17) is known to be small at atmospheric temperatures (Henry, 1948), there is little doubt that a better fit with the experimental data would be obtained by substituting an experimental ultimate value for $\triangle_o M$ in equation (17). The small discrepancy found between (17) and the equation to be obtained by substituting from (4)–(8), (12), and (20) together with the definition of D in equation (10) would not affect this position. However, this proposed substitution of an experimental figure for $\triangle_o M$ presupposes a knowledge of the weight changes that are going to take place during storage, which information would not be available for the present purpose of predicting weight changes in baled wool. There remains one further approach to the problem. It should be possible to predict approximate equilibrium bale weights in the final atmospheres from a knowledge of the characteristic regain of wool in equilibrium with atmospheres of specific temperatures and relative humidities (if the effects of hysteresis are neglected). No self-consistent experimental investigation is known of the equilibrium regain of wool over the range of temperatures and humidities covered by the present experiments. However, W.I.R.A. (1955, p. 20) have demonstrated that values of regain calculated (Shorter, 1924) from Speakman's (1930) desorption values at 25°C are consistent with Weigerink's (1940) measured desorption values at other (higher) temperatures. W.I.R.A. (1955, p. 9) have smoothed and summarised Speakman's (1930) regain curve for clean wool at 25°C; and for simplicity averages of absorption and desorption values of relative humidity on this curve were converted (at each value of regain) to other temperatures by means of the Clausius-Clapeyron equation (Glasstone, 1956), using values for the heat of reaction between wool and liquid water (assumed invariant with temperature) based on the data summarised by W.I.R.A. (1955, p. 18). These relationships are shown in Fig. 18. By employing a definition of relative humidity as the ratio of water vapour concentration to the concentration at saturation (B.S.I., 1953), the temperature and relative humidity of the ambient atmospheres were used to determine equilibrium regain values for clean (i.e., grease-free wool) from Fig. 18. By comparing these with the corresponding figures of regain for the wool in the bales at the commencement of each experiment (1A to 6A), values of $\triangle_o M$ were calculated; assuming in each case that the experimental regains determined by drying with room air at 105° to 110°C (B.S.I., 1953) would be $\frac{1}{2}\%$ lower than Speakman's (1930) values of regain determined by chemical drying (Barker and Hedges, 1926). The values of $\triangle_o M$ thus determined were substituted in equation (17) together with the experimental parameters and diffusion coefficients shown in Table 1, and the diffusion functions of Table 3 were combined with these results to yield the curves shown dotted in Figs 11 to 16. In the case of bale 7A the value of water vapour concentration at −11°C (Table 1) is inadequate to establish a value of regain, so no dotted curve is shown in Fig. 17.

The results of the present experiments demonstrate that the pre-conditioning times shown in Table 1 (Part 1) would be inadequate to ensure

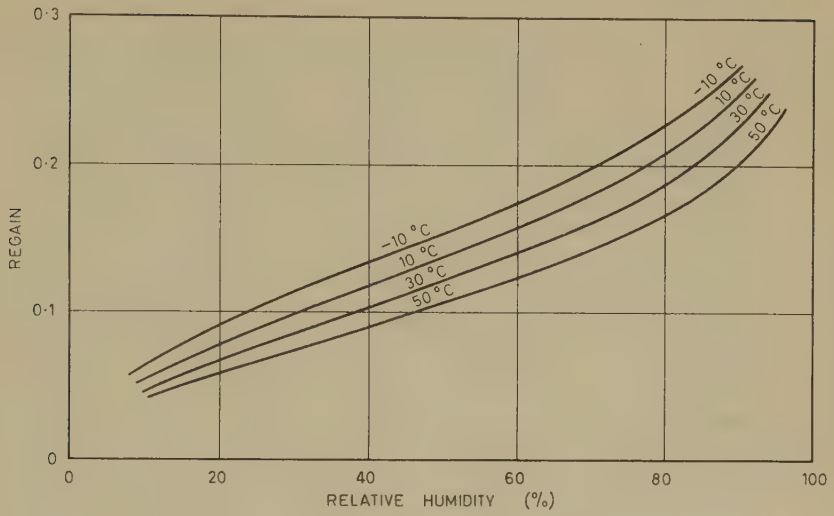

FIG. 18—Calculated regain equilibria for clean wool.

moisture equilibrium throughout each bale. However, all bales except 6A and 6B (see Part 1) were conditioned to a point where the gross weight change was less than 70 g per day (generally much less). In the case of those bales initially at a temperature below freezing point, vapour movements would be small. It is therefore considered that except for bales 5A and 5B, the residual inequalities of moisture distribution would have a negligibly small effect on these experiments, and on the present applications of theory and those in Part 1 (Figs. 1 to 7).

Henry (1939) first showed that in any bulk textile material a diffusing front of either water vapour concentration or of temperature will be divided between a fast wave (f_2) and a slow wave (f_1). He showed that if no coupling existed between these two processes, the f_1 vapour concentration wave would have an amplitude $\triangle_0 C$, and the f_2 temperature wave an amplitude $\triangle_0 T$. He therefore suggested that in the case of coupled diffusion a $\triangle_0 C$ amplitude of f_1 wave should be regarded as a permanent wave of water vapour concentration, and a $\triangle_0 T$ amplitude of f_2 as a permanent wave of temperature, disturbed in each case by an appropriate amplitude of a temporary wave consisting of the difference between f_2 and f_1. Cassie and Baxter (1940) carried out a diffusion experiment with cotton in which the ambient temperature was suddenly raised whilst the concentration of water vapour was held constant, and demonstrated that in this case the temperature change is propagated in two well-defined fronts which add to give the total temperature change. By a re-arrangement of Henry's equations Cassie and Baxter (1940) showed that theory is consistent with these two observed fronts. For this reason they argued that both waves are permanent, contributing about equally to the temperature change in their experiment. Henry (1948) later defended his initial view. As equation (7) shows, variations in bale temperature caused by a change in ambient tem-

perature are permanent, since the f_2 and f_1 waves add to make up $\triangle_0 T$. Variations in bale temperature caused by a change in ambient water vapour concentration are temporary, since the f_2 and f_1 waves are opposed and equal. This temporary wave may be positive or negative. When changes are made simultaneously in both ambient temperature and water vapour concentration, equation (7) shows that the resulting f_2 and f_1 temperature waves may aid or oppose one another, depending on the relative magnitudes and signs of $\triangle_0 T$ and $\triangle_0 C$. Although these two temperature waves add in most of the present experiments, an example of opposition is shown in Fig. 5. Equation (8) shows that a similar pattern of events will hold for $\triangle_0 C$. However, although the f_2 wave for water vapour concentration within the bale may have a large magnitude, this is prevented by the accompanying f_2 temperature changes from having any appreciable effect on regain. Equation (21) shows that when changes are made in ambient water vapour concentration, the f_2 and f_1 regain waves add to give the final regain change, the f_2 wave being small. When changes are made in ambient temperature, the f_2 and f_1 regain waves act in opposition, and the f_2 wave is small. When simultaneous changes are made in both ambient temperature and water vapour concentration, equation (21) shows that the resulting f_2 and f_1 regain waves may aid or oppose one another, depending on the relative magnitudes and signs of $\triangle_0 T$ and $\triangle_0 C$. Again, the f_2 (or F_2) wave is small in all cases. The presence of an F_2 wave in regain was not observed experimentally in any of the present experiments.

Whilst it is obviously possible to visualise many physical interpretations of a mathematical expression, the appropriate concepts are those that assist a physical understanding of the phenomena involved. The views of both Henry (1939, 1948) and Cassie and Baxter (1940) are mathematically correct, and aid in a physical understanding of the two cases they were studying, respectively the change of water vapour concentration at a constant temperature, and the change of temperature at a constant concentration of water vapour. When simultaneous changes are made both in ambient temperature and ambient water vapour concentration, it is simpler to use equations expressing the respective magnitudes of f_2 and of f_1 (or alternatively of F_2 and F_1) and this also simplifies computing. The present experiments together with those of Cassie and Baxter (1940) and W.I.R.A. (1955, p. 62), show that in the case of both wool and of cotton, the two diffusion coefficients D_2 and D_1 are usually sufficiently different in magnitude to produce a well-marked pause between the f_2 and the f_1 temperature waves. A corresponding state of pseudo-equilibrium is also predicted by the theory for regain diffusion waves, but no experimental verification of this has yet been reported for regain. In the present Figs 1A, 2A, and 4A (and other similar experiments) thermocouples located at various positions in each bale demonstrated that this pseudo-equilibrium temperature is distributed reasonably uniformly throughout the bale. This diffusion pseudo-equilibrium may therefore be compared to the pseudo-equilibrium described by Cassie (1940) and W.I.R.A. (1955, p. 25) for the case of air forced rapidly through bulk wool, and the word "temporary" would be better applied to the state of pseudo-equilibrium rather than to the diffusion waves that produce it.

Crank (1960) has enumerated the various assumptions underlying Henry's theory (1939, 1948), and these are sometimes assumed to represent all limitations to its practical application. However, as Figs 8 and 9 demonstrate, the greatest difficulty in applying the theory to bulk wool is probably the fact that σ and ω are not constants. Further minor complications arise in the case of greasy wool, since little is known of the water relationships of the grease and suint. The experiments in Part 1 demonstrate good agreement in predicting the pseudo-equilibrium temperature between the f_2 and f_1 waves, but poor agreement over the magnitudes of D_2 and D_1. The present measurements of weight changes are erratic, but Figs 11, 12, and 14 show reasonable agreement over both the magnitudes of the weight changes and of the D_1 diffusion coefficients. It is obvious that more experimental investigation will be required before the theory can be applied with confidence to bulk wool in practical examples, but the present experiments demonstrate potentialities. Most commercial changes in ambient atmosphere are gradual, rather than the sudden changes employed here; but Henry (1939) has shown that this need not handicap application of the theory, since continuous changes can be regarded as the limit of many small sudden changes. Although practical application to weight changes in bulk wool is as yet unproven, the theory is sufficiently interesting to justify working out an example. One problem of commercial importance in New Zealand is that of conditioning wool after machine drying. It is not uncommon for wool to be over-dried in machine-driers (Pressley, 1956; Rothbaum and Vere-Jones, 1960), and then to be stored in large bins to reabsorb an equilibrium moisture content from the atmosphere. These bins vary in shape and dimensions, but a floor area 12 ft by 10 ft can be taken as an example, enclosed on three sides and bottom with wooden boarding, and filled with wool to a depth of 4 or 5 feet. This wool is commonly piled at a bulk density of about 0·03 to 0·04 g cm^{-3}. For calculation of water vapour diffusion this can be taken as a plane parallel half-slab of effectively infinite extent, and depth about 120 cm. Consider a case where wool containing 10% grease is over-dried to say 5½% regain (B.S.I., 1953), and is then blown through a duct into the bin by a draught of air at say 20°C and 70% RH. Cassie (1940) has shown that when wool is ventilated with an excess of air at a temperature and a concentration of water vapour other than those with which the wool would be in equilibrium, it will rapidly assume a temperature to bring it into regain equilibrium with this air. The data presented by W.I.R.A. (1955, p. 25) show that in the present case the wool (at this initial regain of 0·06 on the clean oven-dry weight) would thus assume a temperature of 31°C. If the effects of hysteresis are neglected, Fig 18 shows that this wool would attain ultimate equilibrium with an atmosphere of 20°C and 70% RH by absorbing water to a final regain of about 0·17 (on the clean dry weight). The conditions of mid-temperature and mid-regain are thus 25½°C and 0·12 regain (on the clean dry weight), and Figs 8 and 9 yield $\sigma = 7800$ and $\omega = 0{\cdot}0056$. If a bulk density of 0·035 g cm^{-3} is assumed, γ would be little different from this (0·036 g cm^{-3}). Little information is available on the thermal conductivity of wool at this bulk density, but Finck (1930) has shown that the values of thermal conductivity for dry fibrous organic materials commonly pass through a minimum as bulk density is lowered to about 0·1 g cm^{-3}, and

then rise with further decrease in bulk density. By applying Finck's interpretation (1930) to the experiments described by Baxter (1946b), and allowing for the presence of the regain moisture, a thermal conductivity of about $0{\cdot}85 \times 10^{-4}$ could be assumed. There is similarly little information available on the diffusion coefficient of water vapour in wool of this bulk density, but Baxter's experimental results (1946a) suggest that it would have a value little different from the value in free air, perhaps 0·25 cm^2 sec^{-1}. When applied to equations (2) and (3), these parameters yield $D_1 = 4{\cdot}0 \times 10^{-4}$ and $D_2 = 130 \times 10^{-4}$. Equation (21) then predicts a gain in regain (on the clean dry weight) of 0·102 for the f_1 wave, opposed by a loss in regain of 0·0005 for the f_2 wave. By assuming that the wool in the bin would act as a plane half-slab of infinite extent, the values of diffusion parameters presented by Henry (1939) can be applied to these data to predict values of regain in the bin after specific time delays. Fig. 19 shows these regain values (calculated on the oven-dry greasy

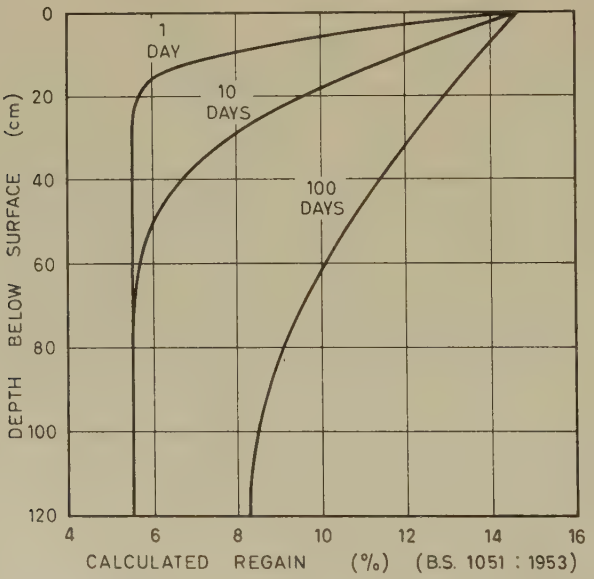

FIG. 19—Calculated regain gradients in a bin of over-dried wool.

weight – B.S.I., 1953) after delays of 1, 10, and 100 days (and assuming that the wool is left undisturbed in the bin). This calculation represents an extreme case in delayed attainment of equilibrium regain, since the walls and floor of the bin would allow some permeation of water vapour, and would certainly permit some conduction of heat. Moreover, it is normal practice to turn the wool over in the bin from time to time. These three effects would all speed the attainment of equilibrium. Moreover, the experimental results in the present work suggest that the D_1 values predicted by Henry's theory (1939) using the present parameters and

diffusion coefficients may be too small, again suggesting that equilibrium may be attained more rapidly than shown in Fig. 19. The final test must be one of experiment, rather than the present theoretical calculation. However, within the likely magnitude of all these effects, Fig. 19 suggests that conventional binning for one or two days is unlikely to have an appreciable influence on the regain of wool that has been over-dried, and demonstrates the importance of adequate control of the wool-drier (Rothbaum and Vere-Jones, 1960). Deliberate over-drying of slipe wools has been a common practice in New Zealand as a result of the conclusion drawn by the New Zealand Royal Commission to Inquire into Fires on Wool Ships (N.Z. Royal Commission, 1907) that excessive moisture in wool can cause spontaneous ignition. Walker and Harrison (1960) have shown that wool must be thoroughly dried if microbiological heating is to be avoided, but concluded that such heating could not of itself cause ignition of wool.

In conclusion, it is interesting to note that Edmunds (1961) has reported moisture gradients of 3% to 4% regain in commercial bales of scoured wool. His measured gradients have a form not unlike the 100-day contour shown in Fig. 19 (see also Henry, 1939).

CONCLUSIONS

1. A form of Henry's equation can be deduced to predict weight changes in baled wool when the ambient atmosphere has been changed, without requiring empirical determination of regain under the new conditions.
2. Although insufficient experiments have been carried out for generalisations to be made, Henry's theory has been successful in some cases for predicting weight changes in wool bales suddenly exposed to changed atmospheric conditions.

ACKNOWLEDGMENTS

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A BACTERIOLOGICAL SURVEY OF POLLUTION OF THE FORESHORE AND RIVERS IN THE HASTINGS DISTRICT, NEW ZEALAND

By H. M. Stone, Dominion Laboratory, Department of Scientific and Industrial Research, Wellington.

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Summary

A bacteriological survey has been carried out, between February and April 1961, of the foreshore between Clifton and the Tukituki River, and the tidal reaches of the Tukituki, Ngarururoro, and Tutaekuri rivers in the Hastings district, New Zealand. The Hastings City sewer outfall is on the foreshore between the Tukituki and the Ngarururoro rivers, and the Whakatu freezing works and other industries discharge into the Ngarururoro River.

The Ngarururoro and Tutaekuri rivers are shown to be considerably polluted from upstream Ngarururoro sources, but it is not possible to determine from the results of this survey whether sewer-polluted sea-water contributes to the polluted condition.

The Tukituki River is polluted from a non-saline source inside the mouth, and the high coliform figures obtained make it impossible to determine the extent of sewer-polluted sea-water penetration.

Haumoana Beach is shown on one occasion to be in a polluted state, and the sewer outfall is considered as the most likely source of pollution.

Membrane filter techniques for determination of *E. coli* I and faecal enterococcus, and tube dilution techniques for *E. coli* I, are discussed.

Introduction

This survey was undertaken at the request of the Pollution Advisory Council for a bacteriological investigation into the extent and sources of pollution in the lower regions of the Tutaekuri, Ngarururoro, and Tukituki rivers, and the foreshore between the Tukituki River and Clifton. The investigation was carried out between February and April 1961. Since some of these areas are, or could be, used for recreational purposes, it was intended that particular emphasis be placed upon the possibility of pollution of these areas from the sewer outfall on the beach at East Clive.

Situated in this area are the Tomoana and Whakatu Freezing Works, two woolscouring works, food processing factories and other industries. At the time of the present investigation, these industrial wastes were being discharged partly into the Karamu Stream (a tributary of the Ngarururoro River) and the Ngarururoro River, and partly into the sewer carrying domestic waste from Hastings City. An additional sewer, also to discharge at East Clive, is being built to carry the bulk of the industrial waste at present discharging into the rivers, and is expected to be in operation late 1961, or early 1962.

The Ministry of Works, with the cooperation of the Department of Health, the Dominion Laboratory, D.S.I.R., and Napier Public Hospital, carried out a survey in 1957 into the sources and types of pollution in

this area. Their findings were presented to the Pollution Advisory Council in a cyclostyled report entitled "Pollution in the Hastings Area". The report adequately covers a description of the area, population, industries, future development, use and condition of the waters, disposal methods, etc. The present survey does not duplicate that report. Bacteriological and chemical testing facilities available at the time of the 1957 survey were extremely limited, and a systematic sampling survey was not possible. The purpose of the present small-scale survey is to provide a preliminary bacteriological coverage of existing conditions.

METHODS

Intensive sampling was carried out on 28/2/61, 1/3/61, and 2/3/61, samples being examined within 3 hours of sampling. In addition, by special arrangement, a limited number of samples taken by an officer of the Health Department, Napier, on 10 and 17 April 1961, were sent by air to Dominion Laboratory, Wellington, and examined the same day and the following day respectively. Assistance with sampling was provided by the Health Department, Napier, and the Hastings City Council.

The principal bacteriological method used was membrane filtration of selected volumes of sample, pre-incubation at 37°C on nutrient broth for 2 hours, followed by transfer to a modified MacConkey Broth medium and incubation at 44°C ± 0·1°C for 12–18 hours, and selective colony counting by means of a low-power microscope. Details of the method are described by Taylor *et al.* (1955). Results, available the morning after the sampling, assisted in planning further work. Bacteriological results were expressed as *E. coli* I/100 ml of sample. Previous experience has shown that positive colonies on this modified MacConkey medium at 44°C confirm invariably as *E. coli* I (IMVIC tests) and indefinitely positive colonies, of which a proportion confirm as positive *E. coli* I, are few in relation to the number of definitely positive colonies present. Duplicate analyses generally compare closely. In the author's experience this method is sensitive to a wide range of pollutional levels, gives reproducible results quickly, and is therefore considered very suitable for this type of work. Samples analysed at Dominion Laboratory were also examined for faecal enterococcus by the membrane filter technique of Slanetz and Bartley (1957).

To compare methods, some of the samples were examined by multiple tube dilution using MacConkey broth at 37°C (M. of Health 1956), with 3 tubes at each of 4 serial dilutions. Positive tubes were sub-cultured into brilliant green bile broth for incubation at 44°C. and peptone water for indole production at 44°C. positive tubes in both media being accepted as sufficient confirmation of the presence of *E. coli* I. Results of the 37°C and 44°C tests are expressed as Most Probable Number (MPN) coliform organisms/100 ml, and MPN *E. coli* I/100 ml, respectively.

A mud sample was examined by shaking a weighed amount of mud with 9 times its weight of sterile Ringer's solution, allowing the mud to settle, then applying membrane filtration to the clear liquid and incubation as for the water samples. The result is expressed as *E. coli* I/g of sample.

All bacteriological results shown on the maps are *E. coli* I/100 ml determined by membrane-filtration technique, and references to coliform organisms in the text are to *E. coli* I as determined by this method unless otherwise stated.

The samples were kept for subsequent determination of total salts by measurement of electrical conductivity. Conductivities were compared with those of a standard Danish sea-water of 3·499% salts, and dilutions of the standard water. The results are expressed as per cent salinities, relative to the set of dilutions of the standard. Undiluted sea-water would have a relative salinity of approximately 100, and infinitely diluted sea-water, a relative salinity of nil. Conductivity measurements on sea-water samples were made by the N.Z. Oceanographic Institute, D.S.I.R.

Fig. 1 shows the locality, and Fig. 2 the numbered sampling positions established for this survey.

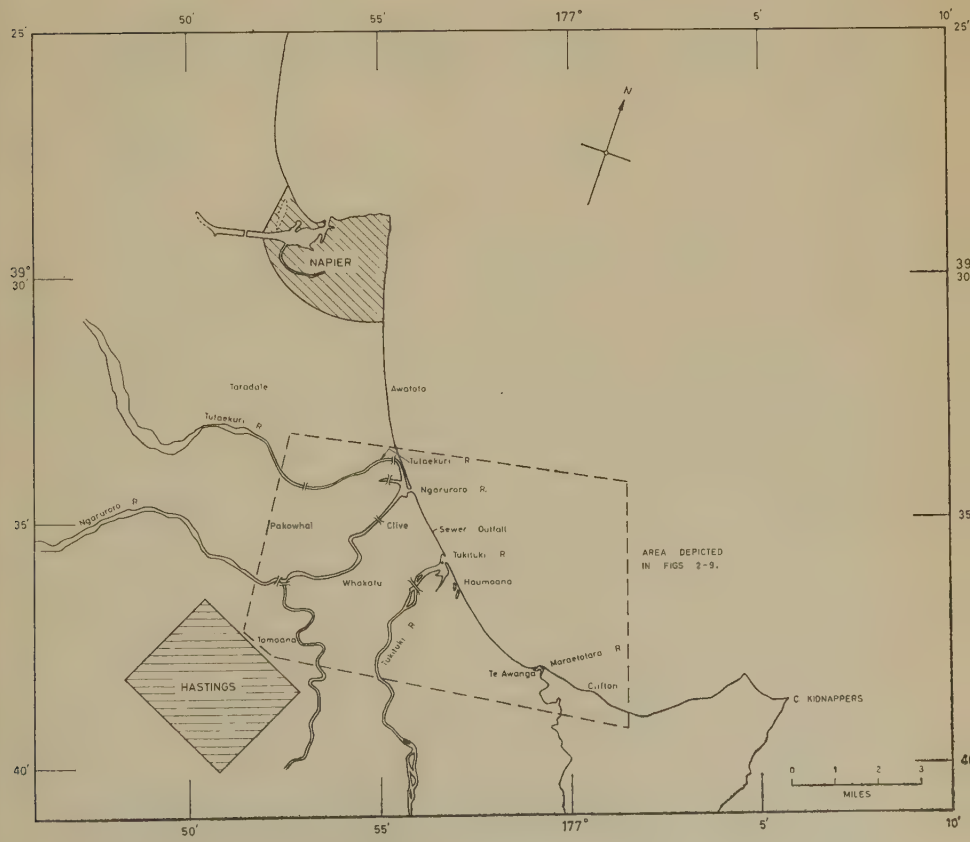

FIG. 1—Locality map.

RESULTS

The results of coliform level and salinity determinations together with relevant details of tidal stages, weather, wind, and sea conditions are shown in Figs 3–9. As the topography was flat it was difficult to observe the direction of river-water drift in the sea, but whenever an apparent sewage drift was obvious, this is recorded in the captions. Samples were taken over short periods of time in order that results could be plotted as though they had all been taken simultaneously.

A few Ngarururoro River samples were taken near the river bottom and the results are shown in Table 1 together with corresponding surface sample figures and references.

TABLE 1—Coliform and Relative Salinity Figures on Depth Samples

Date	Sampling Position	Depth of Samples (ft)	*E. coli*/ 100 ml (M.F.*)	Relative Salinity (%)	Reference, for Sampling Conditions
28.2.61	4	Surface	950	2·5	Fig. 3
	4	5	8300	15	Fig. 3
28.2.61	4	Surface	400	18	Fig. 4
	4	13	120	95·1	Fig. 4
28.2.61	47	Surface	170	0·4	Fig. 4
	47	4	450	—	Fig. 4
28.2.61	48	Surface	260	0·3	Fig. 4
	48	3	160	—	Fig. 4
2.3.61	46	Surface	2200	0·7	Fig. 6
	46	6	2200	38	Fig. 6
2.3.61	48	Surface	4500	0·35	Fig. 6
	48	2	2000	1·3	Fig. 6

*Membrane Filtration.

The coliform figures shown in Figs 8 and 9 are also shown in Tables 2 and 3 together with faecal enterococcus and any tube dilution coliform figures. Duplicate samples were taken to test the reproducibility of the methods.

TABLE 2—Results of Faecal Enterococcus and Coliform Tests by Membrane Filtration, and Coliform Tests by Multiple Tube Dilution, 10.4.61.

Sampling Position	Faecal Ent./100 ml	*E. coli* I (M.F.)/100 ml	MPN/100 ml Coliforms	MPN/100 ml *E. coli* I
4	250	550	2400	930
4	140	540		
40	65	120	930	240
40	55	85		
42	20	85	750	390
42	40	90		
48	95	480	930	430
48	300	480		
6	70	85	240	93
5	15	20		
15	5	45		
14	10	30		
14	10	40		
13	95	250		
13	60	320		
52	45	900		
52	80	1500		
Maraetotara River	25	40		
	20	50		
Te Awanga Lagoon	105	120		
	30	85		
30	0	15		
30	5	10		
31	0	30		
31	0	0		
32	25	45		
32	40	30		

TABLE 3—Results of Faecal Enterococcus and Coliform Tests by Membrane Filtration, and Coliform Tests by Multiple Tube Dilution, 17.4.61

Sampling Position	Faecal Ent./100 ml	*E. coli* I (M.F.)/100 ml	MPN/100 ml Coliforms	MPN/100 ml *E. coli* I
10	830	1900		
11	1100	1600		
12	1000	1000		
14	100	30	93	43
15	25	15	150	39
53	760	700	11,000	1500
13	500	650	2400	930
52	370	1350	4600	750
16	270	430	930	240
17	40	120		
18	60	85		
19	130	840		
20	95	95		
21	75	95		
22	60	135		

FIG. 2—Numbered sampling positions established for the survey.

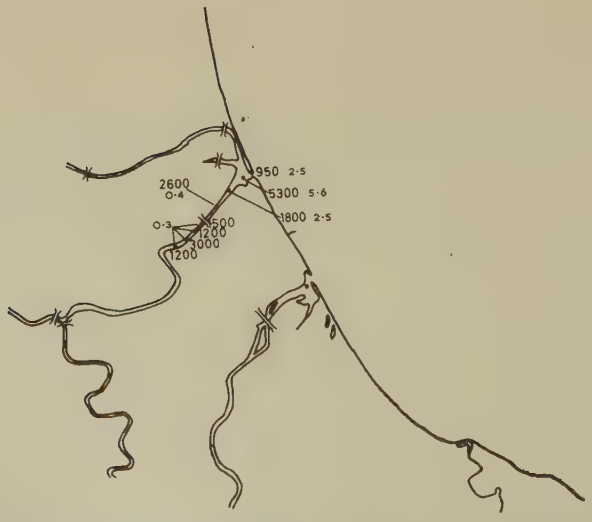

FIG. 3—Coliform (larger type) and relative salinity (smaller type) figures; Tuesday 28.2.61, 0955–1030 hr.
Low water 1025 hr. Weather fine.

FIG. 4—Coliform (larger type) and relative salinity (smaller type) figures;
Tuesday 28.2.61, 1430–1620 hr.
High water, 1607 hr. Weather fine.
Sea, mod. calm. Wind, N.E., 5–10 m.p.h.
Drift, appeared to be to N.

FIG. 5—Coliform (larger type) and relative salinity (smaller type) figures;
Wednesday 1.3.61, 0930–1130 hr.
Low water, 1105 hr. Weather, slight drizzle overnight and during sampling.
Sea, almost calm. Wind, S.W. 5–10 m.p.h.
Drift, appeared to be to N.

FIG. 6—Coliform (larger type) and relative salinity (smaller type) figures;
Thursday 2.3.61, 0600–0630 hr.
High water, 0507 hr. Weather, light rain overnight and during sampling.

FIG. 7a—Coliform (larger type) and relative salinity (smaller type) figures;
Thursday, 2.3.61, 1015–1115 hr.
Low water, 1145 hr. Weather, light rain overnight.
Sea, calm. Wind, very light N.E.
Drift to N.

FIG. 7b—Coliform (larger type) and relative salinity (smaller type) figures;
Thursday 2.3.61, 1445–1510 hr.
High water, 1728 hr. Weather, light rain overnight.
Sea, 2 ft swell. Wind, E.N.E., 10–15 m.p.h.
Drift appeared to be to S.E.

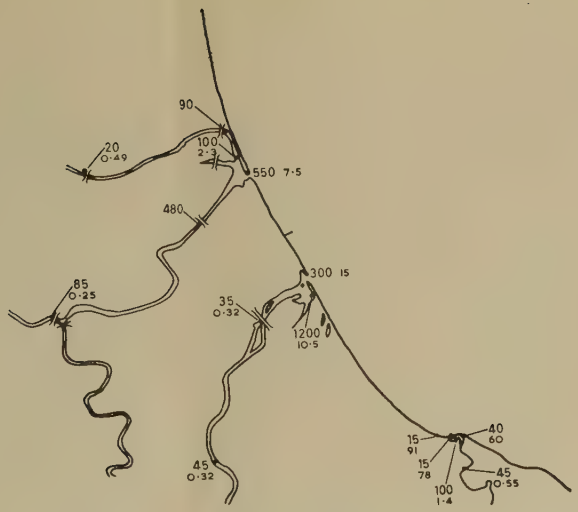

FIG. 8—Coliform (larger type) and relative salinity (smaller type) figures;
Monday 10.4.61, 0510–0800 hr.
Low water, 0545 hr. Weather fine.
Sea, calm. Wind, calm to light S.W.
Drift to N.

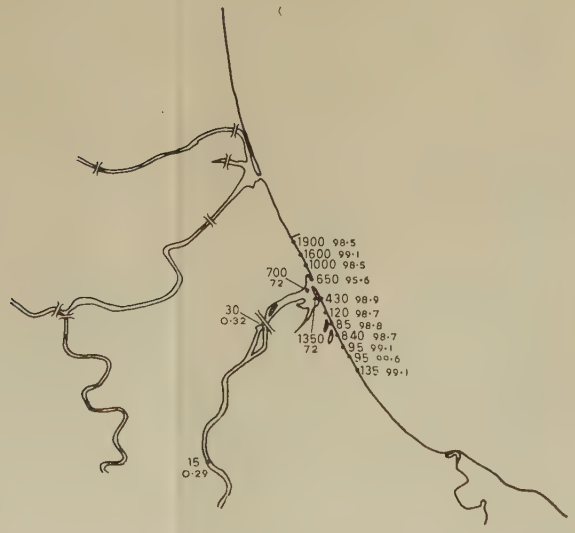

FIG. 9—Coliform (larger type) and relative salinity (smaller type) figures;
Monday 17.4.61, 0630–0820 hr.
High water, 0700 hr. Weather fine, followed by drizzle.
Sea, calm, later choppy. Wind, calm, to N.W. 20 m.p.h., and calm again.
Drift, towards Cape Kidnappers.

Samples taken on 17.4.61 could not be examined until 18.4.61 after standing 24 hours in the dark at ambient temperature. To ascertain the effect of this standing time on the coliform counts obtained, 6 samples selected as being a cross-section of the 15 involved, were examined on 3 successive days. The results are shown in Table 4.

TABLE 4—Effect of Standing Time at Ambient Temperature on *E. coli* I Count (M.F.)

Sampling Position	*E. coli* I/100 ml		
	18.4.61	19.4.61	20.4.61
21	95	60	5
19	840	—	200
17	120	70	15
52	1350	600	10
53	700	1300	170
12	1000	700	150

DISCUSSION OF RESULTS

The Pollution Advisory Council has published tentative standards for bathing waters (Ministry of Works 1959), requiring coliform bacteria of human intestinal origin not to exceed 500 per 100 ml, or where such limits are readily obtainable, 100 per 100 ml.

Ngaruroro River

The salinities of surface samples taken at the Clive Bridge (Fig. 2, position 48) ranged between 0·3% to 0·35% irrespective of different times and tidal stages (Figs 3, 4, 5, 6, 7). The minimum salinity of 0·25% at the Pakowhai Bridge (position 6) and a salinity range of 0·3% to 0·35 obtained up to ½-mile upstream, indicate that surface water in this stretch of the river is not appreciably mixed with sea water at any stage of the tide. Depth samples taken on 2.3.61 at high water on a tide close to a spring tide and shown in Table 1, show that sea water could penetrate as far as the Clive Bridge.

In the region between sampling points 46 and 51 the surface coliform figures appear to be related to the day of the week on which the samples were taken. Monday and Tuesday sampling showed lower coliform densities as instanced by Fig. 3, 1200–3000, Fig. 4, 130–360, and in Fig. 8, 480 at the Clive Bridge. Samples on Wednesday or later in the week gave densities of, in Fig. 5, 7500; Fig. 6, 4500; Fig. 7a, 3800. These positions, being unaffected by sea-water pollution on these occasions, indicate the degree of pollution from upstream sources. It is apparent that the daily pollution load of the river does not clear overnight. Early morning samples show that the river is highly polluted, and probably remains so all week; the pollution is reduced during the weekend. A coliform figure of 85 was obtained at the Pakowhai Bridge (5 miles upstream, and above the Whakatu Freezing Works).

Penetration of Sea Water into the Lower Reaches of the Ngaruroro River

Sampling to estimate the extent to which sea water penetrates the lower reaches of the Ngaruroro can only satisfactorily be done at a time when the pollution load of the river is small, which from this survey, appears to be restricted to Mondays. Salinity figures are markedly higher at 46, 45, 4 (Fig. 3) and the depth sample at 4 (Table 1). At 45 (Fig. 3) and 4 at 5 ft (Table 1), high coliform figures were also obtained. The stratification at 4 of a high-coliform-level salt-wedge beneath the lower-count, less-saline upper layer is significant. As these samples were taken at low water, it is likely that, at 46, diluted sea water is returning downstream. Samples from the same positions at high water (Fig. 4) show penetration of sea water as evidenced by the high salinities at 39, 40, and to a lesser extent 46, but these figures are not associated with high coliform figures. It can be assumed that drift from the sewer outfall was not affecting the Northern coast line on this occasion. This is supported by low coastal coliform figures, and salinity figures showing dilution of sea water with fresh water from the river mouth. This outflow of fresh water would tend to protect the shore line from pollution from sewage drift.

Tutaekuri River

Consideration of the salinity figures at positions from 39 to 42 in Figs 4, 5, 7 and 9 shows that at least on 3 occasions, surface water was unaffected by sea water beyond position 41. The lowest coliform figures were obtained from Monday samples (Fig. 8) but the significance of this is not clear, since it is not known whether there is a significant source of pollution in the Tutaekuri River other than from cross-currents from the Ngaruroro River. A sample of mud taken at position 40 gave a count of approximately 10,000 *E. coli* I/g and the possibility of coliform breeding in the mud must be considered. This could account for the high figures obtained in this position and shown in Figs 4 and 5. The limited sampling programme does not allow further conclusions to be drawn other than that the river from the bridge to the mouth on the occasions tested was, with the exception of two samples (Fig. 4), less polluted than the Ngaruroro from Clive Bridge to the mouth. It was not possible to assess the relative contributions to the pollutional state of the Tutaekuri by the Ngaruroro River, the sewer outfall, upstream sources, and the coliform-containing muds.

Tukituki River

The Tukituki is a comparatively unpolluted river. Positions 14 and 15 in Figs 8 and 9 give low coliform figures and consistent low salinity figures. Salinity figures show that penetration of sea water is as far as position 56 (Fig. 5) but unlikely to be beyond the bridge at position 14 (Figs 8 and 9). Appreciable coliform counts were found up as far as position 56 (Fig. 5) and particularly at position 52. In Figs 7, 8, and 9 the high coliform counts at position 52 suggest that the stream or back-water flowing into the river at this point constitutes an additional pollution

source. In fact, on all occasions, the coliform figures at 52 were as high as or higher than at the mouth and other positions on the river, suggesting the stream as the major source of pollution. Much of the pollution, if not the bulk of it on some occasions, might be due to this source.

Once again, because of this additional pollution source, it becomes impossible to show whether polluted sea water is polluting the tidal zone. However, evidence exists for sea-water pollution of this area, in the form of detrita of sewer origin visible on the shore at positions 13 and 53 on 2.3.61 (Fig 7). However aesthetically undesirable these deposits may be, there is still no evidence from this survey that sewer-originated bacterial contamination of the tidal zone of the Tukituki River exists to any greater degree than pollution from the source mentioned at position 52. The existence of this source, which can pollute the stream to a coliform level of 4500/100 ml, is itself a matter of concern.

Clifton Beach

Samples were taken at Clifton beach on two occasions; on 28.2.61 prior to high water under calm light easterly conditions (Fig. 4), and on 1.3.61 prior to low water, with calm sea, light south-westerly conditions (Fig. 5). On both occasions, sewage drift appeared to be tending northerly. Coliform counts were low and salinity figures showed negligible fresh water dilution.

Te Awanga

Samples were taken at Te Awanga on the same occasions and conditions as for Clifton and additionally on 10.4.61 (Fig. 8) under similar conditions to those on 1.3.61. There is evidence of a low-level source of pollution on the beach arising from the river and lagoon at Te Awanga. The low salinity figures on all 3 occasions, the coliform figure of 150 (Fig. 5), the coliform figures on the lagoon and the beach (Fig. 8) and the faecal enterococcus figures (Table 2) all point to this conclusion.

Haumoana

Haumoana beach was sampled on two occasions, the first being at low water, light south-west wind, and sea almost calm (Fig. 5). The drift appeared to be northerly. Salinity figures show slight dilution of sea water all along the beach from Haumoana to Te Awanga, but this could be due to any of a number of causes, principally seepage from lagoons and dilution with fresh water from the Tukituki River. The higher counts at 17 and 18 could arise from either or both of these factors with or without the possibility of sewer-outfall pollution. It is not possible to differentiate them on this day, but it is considered that with the salinities quite high, coliform figures of 150 and 220 are too high to be due entirely to pollution by the Tukituki.

On the second occasion (Fig. 9), at high water, sea calm to choppy, wind calm, and later north-west, the drift appeared to be towards Cape Kidnappers. High coliform counts were obtained all along the beach as far as samples were taken.

It is considered that the conditions most likely to bring about pollution of the beach south of the Tukituki would be on occasions when the drift is in a south-easterly direction, at high water when the outflow of the Tukituki is at a minimum. Such conditions existed on this occasion. It is therefore considered that the high coliform and faecal enterococci counts found along the beach on this occasion could at least in part be caused by pollution from the sewer outfall. Salinity figures are high, thus eliminating low-level pollution sources, and support the existence of a high-level pollution source. This conclusion is consistent with the findings of a study of inshore surface currents in Hawke Bay, carried out early in 1961 by the N.Z. Oceanographic Institute, D.S.I.R. (N. M. Ridgway pers comm.). No information is available from the present bacteriological survey as to whether high coliform counts would have been obtained further south-east along the beach.

Beach North of Ngaruroro-Tutaekuri Mouth

High coliform figures were obtained on all 3 occasions when sampling was carried out north of the mouth of the Ngaruroro and Tutaekuri rivers (Figs 4, 5, and 7), sampling positions 3, 2, and 1. However, considering that the counts obtained were progressively lower, and salinities were in general progressively higher proceeding north from the mouth, and that drift was tending northerly on each occasion, it is probable that the bacterial condition of the foreshore was governed by the condition of the rivers.

DISCUSSION ON METHODS

Comparison of Membrane Filter Coliform Method for Determination of E. coli *I with Multiple Tube Dilution Method*

Comparisons made on a few representative samples show that in 8 out of 11 samples, lower results were obtained on the membrane technique. Streeter and Robertson (1960) consider results by the 2 methods to be in agreement if the membrane filter count is between 0·3 and 3·0 times the corresponding MPN count, thus allowing for the normal error in the MPN examination. On this basis 10 out of the 11 samples were in agreement, and this is consistent with the author's previous experience of the 2 methods.

Faecal Enterococci

In general, the faecal enterococcus count was lower than the corresponding membrane *E. coli* I count. The log mean ratio, *E. coli* I : faecal enterococcus, by the above methods was 2·5–3. The faecal enterococcus figures shown provide a similar pollution pattern to that of the coliform determinations by membrane techniques.

Effect of Standing Time at Ambient Temperature on E. coli *I Count*

The results in Table 4 show that in general there is a steady bacterial die-off on standing and that the likelihood of coliform densities on the day of sampling being lower than the figures obtained the following day is remote. It may be assumed that the coliform figures obtained on 18.4.61 are certainly not higher than the original figures and are more likely to underestimate the pollutional state.

CONCLUSIONS

1. The Ngarururoro River is considerably polluted from upstream sources and does not clear overnight. Reduction of pollution occurs over the weekend, lower figures being obtained early in the week. The Tutaekuri River is also highly polluted in its tidal reaches, probably in part due to cross currents from the Ngarururoro. The Tukituki River is highly polluted near the mouth from a pollution-carrying stream or seepage at Haumoana.

2. The extent of penetration of sewer-polluted sea-water into the tidal zones of the three rivers cannot be clearly differentiated from the other pollution sources.

3. The beach at Te Awanga is slightly polluted by seepage from the lagoon.

4. Haumoana beach was found on one occasion to be highly polluted, presumably from the sewer at East Clive. The conditions at the time were calm to N.W. wind, calm sea, and high tide.

ACKNOWLEDGMENTS

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A NOTE ON THE FOOD HABITS OF FERAL CATS ON LITTLE BARRIER ISLAND, NEW ZEALAND

By WILLIAM H. MARSHALL, Animal Ecology Division, D.S.I.R., Fulbright Research Scholar, 1960–61.

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Food habits of predators are of particular interest when they can be recorded under relatively clear cut conditions of availability of prey. This was recognised by the late J. S. Watson, who made several trips to Little Barrier Island collecting material for a study of the predator-prey relationships between feral cats, rats, and native birds. Mr Watson examined 94 droppings from feral cats, and the results of this work were the subject of a paper being prepared by Mr Watson at the time of his death on 12 August 1959. The present report describes Mr Watson's results and discusses one aspect of their significance.

Little Barrier Island, approximately 7,544 acres, lies in the Hauraki Gulf about 15 miles from the coast of Cape Rodney, North Island, and has been described by Hamilton (1961).

The only mammalian carnivores on the island are feral housecats, which were first brought to the island well over 70 years ago. Their exact numbers are not known but, since 1932, caretakers have killed as many as 40 cats in some years (Turbott, 1947). Cat droppings are found commonly along the main track leading to the highest point on the island, particularly along the lower parts up to about 1,000 feet, but this may simply reflect the faster rate of decay owing to greater humidity at higher elevation (J. S. Watson, Field Report, 1956).

There are two major groups of prey species available to the cats – (1) migratory sea birds, which nest here during the summer, and (2) resident vertebrates and insects, which are on the island year-round. Thus, from October to March, Cook's Petrels (*Pterodroma c. cooki* Gray) nest by thousands in the forest at the upper elevations between 1,000 feet and the summit, 2,500 feet above sea level (Turbott, 1947). The island has a population of Maori rats (*Rattus exulans* Peale). Watson (1956) indicated that the rat numbers increased during the months of February to May, and that "the population in March contained quite a large proportion (32%) of sexually immature animals, and a relatively high proportion of pregnant females so that the increase in the population at this time of year might be a result of the breeding season". Also, Little Barrier is a bird sanctuary containing a rich fauna of native resident birds, including the Stitchbird (*Notiomystis cincta* Du Bus) now confined to Little Barrier, and supports a varied fauna of invertebrates. The role of cats in this complex is therefore of considerable interest.

Watson collected two series of cat droppings in relatively fresh condition: one, representing winter feeding, was of 44 droppings taken in

August 1956; while the second was of 50 droppings taken in February 1958 representing summer feeding. Watson analysed these droppings and sent certain portions to specialists; the results are shown in Table 1.

TABLE 1—Food Items and Their Occurrence in Two Collections of Feral Cat Droppings from Little Barrier Island

Food	Frequency of Occurrence	
	August 1956 (44 samples)	February 1958 (50 samples)
Maori Rat (*Rattus exulans* Peale)	32	5
SEA BIRDS		
Northern Blue Penguin (*Eudyptula minor novaehollandiae* Stephens)	1	3
Cook's Petrel (*Pterodroma c. cooki* Gray)		23
Fluttering Shearwater (*Puffinus g. gavia* Forster)	1	
Northern Diving Petrel (*Pelecanoides u. urinatrix* Gmelin)		1
Large petrel spp.	2	
Unidentifiable petrel spp.		16
Total (Sea birds):	4	43
RESIDENT LAND BIRDS		
N.Z. Parakeet (*Cyanoramphus n. novaezelandiae* Sparrman)	4	
Tui (*Prosthemadera n. novaeseelandiae* Gmelin)	2	
North Island Robin (*Petroica* (Miro) *australis longipes* Lesson)		1
Pied Tit (*Petroica macrocephala toitoi* Lesson)	2	1
North Island Fantail (*Rhipidura fuliginosa placabilis* Bangs)	1	
Whitehead (*Mohoua ochrocephala albicilla* Lesson)	1	
North Island Kaka (*Nestor meridionalis septentrionalis* Lorenz)	1	
Unidentified spp	7	3
Total (Land birds):	18	5
INVERTEBRATES		
Insects		
Orthoptera—*Macropathus* sp. (Weta)	3	
Hemiptera—*Philaenus trimaculatus* White		1
Coleoptera—*Costelytra zelandica* White	2	
Scolopterus tetracanthus White		1
Chlorochiton sp.		1
Sericospilus sp.		1
Eucolaspis sp.		1
Hymenoptera—*Paracolletes* sp.		2
Unidentified insects	4	1
Ticks		
Ixodes anatis Maskell	7	4
Spiders		
Hexathele sandersoni Todd		1
Unidentified spiders		1
Total (Invertebrates):	16	14

An obvious and interesting contrast is between the high occurrence of resident vertebrates, the rat and native birds, in the August collection and the preponderance of sea birds in the February collection. Cook's Petrels were available for two to three months prior to the time of the February collection, but after nesting they leave the island and are not available to the cats after March. The resident Maori rats and native birds, while undoubtedly increasing during the nesting and breeding season, remain on the island and are available during the winter months of June, July, and August.

Some species represented in the droppings such as the Diving Petrel and Fluttering Shearwater have not been recorded nesting on Little Barrier and were probably therefore washed up dead and eaten by cats on the beaches.

Since only one or two invertebrates of any species were found in any one dropping, they were probably eaten by chance. Of particular interest are the ticks (*Ixodes anatis* Maskell) which were also identified by Mr L. J. Dumbleton from a North Island Kiwi (*Apteryx australis mantelli* Bartlet) from Little Barrier (Mr L. J. Dumbleton, *in litt*). As no feathers of this bird were found in the droppings, the cats may have ingested the ticks whilst using kiwi hiding places as dens.

The relationship between cat predation and the nesting petrel populations cannot be fully understood without knowing how cats catch these birds: whether they catch healthy birds or mostly petrels injured on landing. For the present, these data clearly show the importance of availability of food in determining the food habits of a generalised predator such as the feral cat.

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A TALL-TUSSOCK GRASSLAND COMMUNITY IN NEW ZEALAND

By H. E. Connor, Botany Division, Department of Scientific and Industrial Research, Christchurch.

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Summary

A previously undescribed subalpine tall-tussock community dominated by the grass species *Danthonia rigida* (a narrow-leaved snow-tussock), *Festuca matthewsii*, and *Poa colensoi* is described from inland North Otago. Data on abundance/dominance and sociability of the species are presented, and a sociological analysis is attempted. The results are presented in a slightly informal association table which indicates the main groups of species. Three main subdivisions of the association are recognised and some differential species proposed. A limited comparison is made with other tall-tussock communities.

Introduction

In the last one hundred years the natural grasslands of New Zealand have drawn their share of attention in scientific writings (*vide* Drummond and Leatham, 1959) but much remains to be done before the various types are fully described. Cockayne (1928) sets out a broad classification recognising low-tussock and tall-tussock grassland, in the latter distinguishing red-tussock from snow-tussock communities, and this is still broadly followed today. Later papers including descriptions of natural grasslands are those of Zotov (1938), Barker (1953), Mark (1955), Wardle (1956), and Wraight (1960). Members of the Tussock Grassland Research Committee discuss the little that had been written by 1954 about the snow-tussock grasslands, i.e., those dominated by tall yellowish bunch-grasses of the genus *Danthonia*, locally known as snow-tussocks. Barker (1953) gives the most complete account of the composition and structure of a snow-tussock community, listing the species and giving an estimate of the abundance/dominance and sociability of each.

Attention has recently been drawn (Connor, 1960a) to the importance of *Festuca matthewsii* as a characteristic species in a type of snow-tussock grassland which has not hitherto been recognised as distinct. The purpose of this paper is to provide a description of this community and to make some few comparisons.

Notes on the Nomenclature of Some Tall-Tussock Grasses

There is, and has long been, confusion about the names to be used for the tall-tussock grasses. Zotov (1943) listed certain changes in nomenclature of the genus *Danthonia* and his recommendations have since been widely followed. Recent taxonomic work has led to some new conclusions as a result of which names are here used as follows: The name *D. rigida* Raoul (1844)

(based on Banks Peninsula plants), takes precedence over the later *D. raoulii* Steudel (1855), and strictly belongs to a narrow-leaved snow-tussock lacking a strongly marked keel on the back of the leaf; *D. flavescens* Hook. f. (1864) should be applied only to a very wide-leaved snow-tussock. The distinctive red-tussock was called *D. raoulii* var. *rubra ined.* by Cockayne (1928), but his use, though clear, is nomenclaturally dubious; many recent papers (e.g., Tussock Grasslands Research Committee, 1954, Wraight, 1960) use in a restricted way the name *D. rigida* for the common red-tussock of poorly drained places. Barker's references to *D. flavescens* are interpreted as *D. rigida,* while references by Wraight (1960) to *D. rigida* are to red-tussock (as he indicates parenthetically), while his "small narrow-leaved *D. flavescens*" is thought to be not the true *D. rigida* but still another species as yet undescribed.

AREA STUDIED

The information presented was collected from areas adjacent to the Lindis Pass, and from parts of the Ahuriri and Ohau valleys and the Benmore Range (Fig. 1). Fig. 2 gives an indication of the grassland and the landscape at Lindis Pass. The broad geology of this part of North Otago is indicated in the map in Grindley, Harrington and Wood (1959), which shows a change from greywacke to schist in this vicinity. The type of parent rock underlying each stand is indicated in Table 1. North-west winds bring heavy rain to the Divide; this decreases to 18 inches at Omarama and at the same time desiccation by the nor'-westers increases. Winter snow conditions are those usually found in inland basins and valleys. Extensive grasslands ascending to 5,000 ft are used for sheep grazing under leases administered by the Department of Lands and Survey, and some parts have been burnt many times.

At the Lindis Pass and Benmore there is evidence of earlier forests, and wood charcoal can be found in soils at the Lindis and Benmore (B. J. P. Molloy, pers. comm.). In the wetter western valleys mountain beech (*Nothofagus solandri* var. *cliffortioides*) occurs in patches surrounded by grassland, while further to the north-west, towards the Main Divide, beech forest becomes extensive and grasslands are found only on the valley floors and above the forest. Forest dimples may be seen on the slopes of the Ahuriri and Ohau Valleys.

In grasslands below about 2,500 ft *Festuca novae-zelandiae* and species usually associated with it form a low-tussock community. Above this, *Danthonia rigida* becomes the physiognomically dominant plant, associated at first with *Festuca novae-zelandiae* which is replaced, as altitude increases, by *F. matthewsii.* Within the grassland area being described the only tall shrub of any physiognomic importance is *Carmichaelia petriei* though other small shrubby species are found. At various elevations depending on soil slope and aspect, but often at about 4,500 ft, herb-field or something akin to the "tall tussock herb-field" of Cockayne is found. In the eastern part of the area studied *Podocarpus nivalis* is typical of the higher levels on rocky ground.

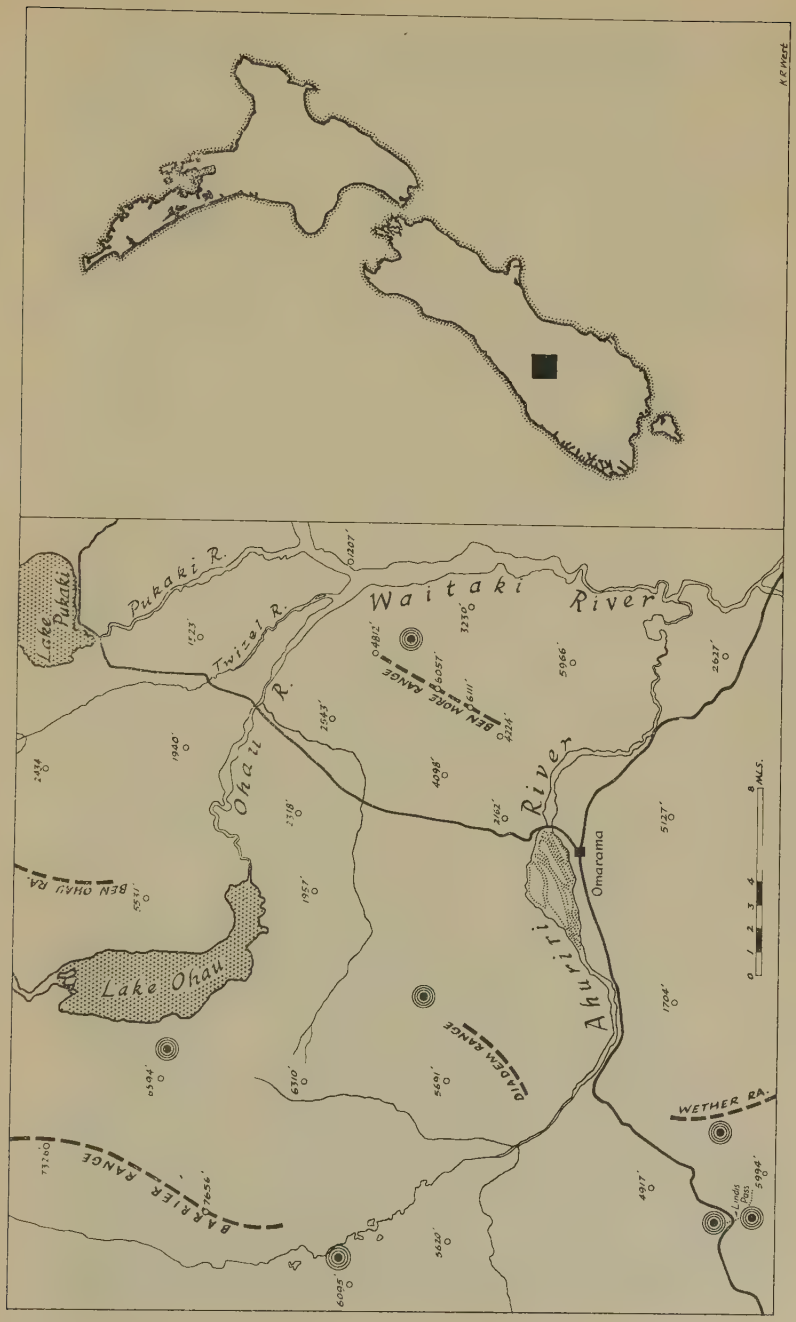

FIG. 1—Locality map. Circles indicate sampling sites.

Whites Aviation Limited photograph.

FIG. 2—*Danthonia rigida* grassland at Lindis Pass.

METHOD

Barker (1953) made use of the concepts and methods of the Zürich-Montpellier school of phytosociology, and a similar approach has been adopted here. Samples of at least 100 square metres were selected after an earlier reconnaissance survey of the stands. For each sample altitude, aspect, slope, percentage bare ground, and parent rock were recorded. Each species listed was given an abundance/dominance value and a sociability rating. Sociability was recorded with emphasis on the number of individuals and their grouping rather than on the grouping of shoots of individuals, e.g., the small cushions of *Scleranthus uniflorus* were most frequently rated ·1 and not ·3 as might be determined from the habit of a single plant.

Looman and Campbell (1960) present an adaptation of Sorenson's K (1948) for estimating unit affinities in prairie vegetation. Calculations of the type they recommend have been carried out and have proved useful in the delimitation of variants of the association described, and have accentuated differences due primarily to a history of burning.

SOCIOLOGICAL ANALYSES

Twenty-two samples at altitudes ranging from 2,100 ft to 4,700 ft were examined in detail and the lists are presented in Table 1. Excluded from the table are species that occurred fewer than three times and these are listed in Table 2. Two species, *Trisetum antarcticum* and *Pimelea* cf. *aridula*, which occurred only twice are exceptions. In two columns adjacent to the twenty-two relevés from the *Danthonia rigida/Festuca matthewsii* association are records from two other stands sampled at the Lindis Pass. These will be discussed separately but are included in Table 1 for comparative purposes. Neither the Degree of Presence nor the species groups used in Table 1 are applicable to these two relevés.

From a consideration of the data in Table 1, the data in Barker (1953) and from much unpublished information it has been possible to separate the following groups of species:

(a) *Snow-tussock grassland species.* Those species which occur only or preferentially in the snow-tussock grasslands. The list does not differ greatly from that of Barker, allowing for differences in location and altitude.

(b) *Widespread tussock grassland species.* Those species found commonly in tussock grasslands whether fescue-tussock, snow-tussock, or even depleted red-tussock grassland.

(c) *Widespread adventive species.* These would be generally accepted as weeds.

(d) *Companion or transgressive species.* This class includes species about which not enough is known to be certain of their status in the

tussock grasslands. Some may be restricted to the association under discussion or may have entered from other communities as transgressors into this one.

Festuca matthewsii has been selected as a *characteristic species* of the association, while five species are cited as differentials of three variants of the association; *Celmisia densiflora* and *C. lyalli* for the high altitude variant of the wetter western valleys, *Cyathodes colensoi* as a differential for lowland stands in the same valleys, with *Trisetum antarcticum* and *Pimelea* cf. *aridula* as differentials for the dry Benmore sites.

A comparison of the individual lists reveals that there are three main subdivisions, relevés 1–9 marked by the number of herb-field species, relevés 20–22 in strong contrast in that there are few or no herb-field species, in fact few herbs at all, and a third (relevés 10–19) intermediate between these two. These three groups may be considered as belonging to one association and show a gradient for the number and kind of species present with the relative dryness or wetness of the area where the samples were taken – more species occurring in the stands from the wetter valleys than in those from the drier Benmore area.

The overall picture of this grassland is that *Danthonia rigida, Festuca matthewsii* and *Poa colensoi* are the most abundant species. The similarity in colour and habit of *F. matthewsii* and *P. colensoi* probably misled previous observers to conclude that *D. rigida* and *P. colensoi* only are present. It can be seen from Table 1 that when the abundance/dominance of the three important grass species is low, a major contribution is made in most cases by *R. subsericea* (presence grade V), though in some relevés *Cyathodes fraseri* (presence grade IV) is quantitatively important, while in the Ahuriri Valley (relevés 1–5) *Gaultheria depressa* was of more significance.

Cockayne (1928, p. 304) states "*the higher the rainfall the larger the herb-field content*" when discussing the rainfall requirements for different classes of grasslands and further on (p. 311) discussing "the *tall tussock herb-field* where *Danthonia Raoulia* var. *flavescens* dominates" observes that it is not easy to draw the line between herb-field and tall-tussock grassland. In this study tall-tussock herb-field characterised by a heavy, spongy, peat-like soil was purposely avoided, emphasis being on the selection of slopes, aspects, soils, and plant communities which were undoubtedly grasslands of the type to be described. There is evident agreement with Cockayne's findings that the herb-field content increases with higher rainfall. Relevés from the wetter western valleys (Nos. 1–5, 6–9) show this markedly when compared with relevés from the drier eastern sites. The gradient is emphasised by the arrangement of species list in Table 1.

With the geographic emphasis in the arrangement of Table 1, closely related though this is to the floristic analysis, some relevés may appear out of place. The site of the stand recorded in relevé 8 was accidentally burned in mid-October 1954, and here *Rumex acetosella, Hyochaeris radicata, Anthoxanthum odoratum* and *Aciphylla aurea* reached higher abundance/dominance values than in any other relevé, and give an indication of the response to burning in this area. *Danthonia rigida* was reduced to a low

level of abundance/dominance, and there is in Table 2 a list of single occurrences in this sample, some of which are probably responses to burning. *Coprosma petriei* and *Discaria toumatou* are not frequent at 3,500 ft in the area studied but both occurred in this stand and may be related to a history of earlier burning. At low altitude on the slopes of Pukemakariri in the Ahuriri Valley (relevé 5 from a stand where forest dimples were obvious), *Leptospermum scoparium* plants were invading from nearby scrub, and *Gaultheria depressa* was abundant. *Coprosma petriei* was also present in roughly the same amount as *G. depressa*, with *Cyathodes colensoi* quite prominent. *Danthonia rigida* was again absent and *Discaria toumatou* present. The conclusion is apparent that here is a reponse to burning comparable with that in the Ohau valley.

Two additional samples (23, 24) are presented in Table 1, but these are not part of the *Danthonia rigida/Festuca matthewsii* association. At the Lindis Pass, at the same altitude, either *F. matthewsii* or *F. novae-zelandiae* can be found associated with *D. rigida* but these three species rarely occur together; the occurrence of *F. novae-zelandiae* in relevé 13 is as an accidental. In this particular area it seems that the upper limit of *F. novae-zelandiae* and the lower limit for *F. matthewsii* meet. At this altitude aspect is the controlling factor, *F. novae-zelandiae* favouring the sunny aspects and *F. matthewsii* the shady ones. This is revealed from a comparison of two pairs of relevés. Samples 23 and 24 were from sunny aspects, north and west, samples 10 and 15 were of shady aspects, south and east. Sample 23 was immediately across a small valley separating it from sample 15 of shady aspect; plot 24 was sited immediately over the ridge which divided it from plot 10 on the shady side. The altitudes of the pairs differed in one case by about 25 ft, and slope was much the same in all four. The first most evident feature from the comparison of the pairs of relevés is the difference in bare ground, there being more bare ground on the plots with sunny aspects, numbers 23 and 24, than in plots 10 and 15. The most evident change in species composition lies in the replacement of *F. matthewsii* by *F. novae-zelandiae*. Along with this major change there are fewer species, but the sample is small and further generalisations would be unwise. The influence of aspect is not maintained, as is seen from relevé 12, and as altitude increases *F. novae-zelandiae* does not appear. At Lindis Pass, at lower altitudes the extensive *D. rigida/F. novae-zelandiae* grassland was not fully sampled so that it is not possible to provide a fuller contrast with the *D. rigida/F. matthewsii* grassland described here in detail.

Among the species listed as companions or transgressor in Table 1, some fill particular niches in the tussock grasslands. The few satisfactorily understood will be commented upon below. *Poa lindsayii* and *Cotula pectinata* occur in inter-tussock spaces where the soil has been bared. *Vittadinia australis* prefers a sunny aspect and is most frequently found in low-tussock grassland. *Plantago spathulata* recorded in relevés 1 and 8 is commonly associated with severely depleted snow-tussock grassland of sunny aspect. *Agrostis subulata* is a high altitude grass. *Linum catharticum*, one of the widespread adventive species, is mostly found in low-tussock grassland but occurs in snow-tussock grassland usually at low altitudes or on sunny aspects.

TABLE 1

EXPLANATION OF SYMBOLS

Estimates of *Abundance/dominance* for each species are given as a single value according to the following scale:

r = of erratic occurrence.
\+ = sparsely or very sparsely present, cover very small.
1 = plentiful but of small cover value.
2 = very numerous or covering at least $^1/_{20}$ of the area.
3 = any number of individuals covering $\frac{1}{4}$ to $\frac{1}{2}$ of the area.
4 = any number of individuals covering $\frac{1}{2}$ to $\frac{3}{4}$ of the area.
5 = covering more than $\frac{3}{4}$ of the area.
( ) = indicates occurrence outside plot but within the stand.

The *Sociability* of each species is estimated—

1 = growing one in a place, singly.
2 = grouped or tufted.
3 = in troops, small patches or cushions.
4 = in small colonies, in extensive patches or forming carpets.
5 = in great crowds.

In the records the abundance/dominance value is followed by the sociability figure.

Presence Class is calculated for each species and expressed in the following scale:

Class I species present in 1%–20% of the plots.
II species present in 20%–40% of the plots.
III species present in 40%–60% of the plots.
IV species present in 60%–80% of the plots.
V species present in 80%–100% of the plots.

LIFE FORMS

N Nanophanerophyte
Ch Chamaephyte
H Hemicryptophyte
G Geophyte
Th Therophyte

TABLE 1—Floristic Analysis

Relevé No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Presence Class	23	24
Locality	Ahuriri Valley					Lake Ohau				Western Lindis Pass						Eastern Lindis Pass				Benmore Range				Lindis Pass	
Parent Rock	Greywacke					Greywacke		Quat. Sed.*		Schist						Schist				Greywacke				Schist	
Altitude (ft)	4300	4600	4500	3350	2900	3250	3900	3500	3800	3400	3350	3600	4700	3100	3125	4100	4100	3900	3650	3100	2100	3100		3150	3400
Aspect (° True)	40	340	50	80	30	30	70	340	160	150	140	40	10	120	110	0	290	320	140	150	110	15		290	330
Angle of slope(°)	22	36	38	39	31	34	33	29	26	31	32	22	23	34	32	36	28	30	10	27	32	35		30	37
Bare ground(%)	5	40	5	5	15	30	15	10	10	20	5	0	20	5	10	75	50	20	35	15	20	70		75	70
CHARACTERISTIC OF ASSOCIATION																									
H *Festuca matthewsii*	2.2	3.3	2.2	3.3	2.3	2.2	2.2	2.2	1.2	3.3	3.3	2.3	3.3	3.3	3.3	2.3	2.3	3.3	2.2	3.3	4.4	2.2	V		
DIFFERENTIAL SPECIES FOR VARIANTS OF ASSOCIATION																									
H *Celmisia densiflora*	+	+	+	+																			I		
H *Celmisia lyallii*	+	+	+	+											(r)				r				II		
Ch *Cyathodes colensoi*				+	2.1	1.1	+	+															II		
H *Trisetum antarcticum*																					+	+	I		
N *Pimelea* cf. *aridula*																					+	+	I		
SNOW-TUSSOCK GRASSLAND SPECIES																									
H *Danthonia rigida*	4.4	2.2	2.2	+		2.2	3.3	(+)	4.4	2.2	+	4.4	+	3.3	4.4	5.4	4.3	4.3	4.4	3.4		4.4	V	+	(+)
H *Deyeuxia avenoides*		1.1	+	+	+	+	+		+	+	+	+	+	+	+	1.1							IV	1.1	
H *Epilobium tenuipes*	+	+	+		+	+	+		+	+		+		+	+						+		IV		
Ch *Pimelea pseudolyallii*	+		+	+	+	+	+	+	+	+	+	+		+									IV		
H *Lagenophora cuneata*	+	+	+	+	+	+	+		+			+		(+)									IV		
H *Brachycome sinclairii*	+				+					+	+			+	+								III		
H *Anisotome aromatica*				1.2		+	1.3		+	+					+								III		
H *Senecio bellidioides*					(+)	+	+			+	+			1.3	1.2								III		
Ch *Gaultheria depressa*	2.3				2.3	+	2.3							+	(+)								III		
H *Aciphylla aurea*							+	2.2	+				(+)										II		
WIDESPREAD TUSSOCK-GRASSLAND SPECIES																									
H *Poa colensoi*	2.2	2.2	2.2	2.3	1.2	2.2	2.2	2.2	2.2	3.3	3.3	2.3	2.3	2.2	2.3	1.2	2.2	2.2	2.2	2.2	3.3	2.2	V	2.3	2.2
Ch *Raoulia subsericea*	+	3.4	1.3	2.2	3.3	2.3	3.3	2.3	2.2	+	+	1.1	3.4	+	+		2.2	2.2	2.3	+	.	(+)	V	2.3	+
H *Wahlenbergia albomarginata*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+		+	+		V		
H *Viola cunninghamii*	+	+	+		+	+	1.1	.	1.3	+	+	+	+	+	+			+		1.2	1.3		V		
H *Triodia pumila*	1.2	1.2	1.2		1.2				2.3				1.1	1.1		(+)		+					V	+	+
H *Luzula campestris*	+	1.2	+			+	+	(+)	+	+	+	+	+	+	+	+		+		+	+	-	V		
H *Epilobium glabellum*	+	.	+	+	+	+	+	+	+	+	+	+	+	+				+		.	.	+	V		
H *Celmisia gracilenta*	+	+	+	1.1	1.1	+	+	+	.	+	.	.	.	+	+	(+)		+		.	.	.	IV		
H *Deyeuxia forsteri*	1.1	1.2	1.2	1.2	.	+	+	+	+	+	+	.	.	+	+	(+)				.	+	.	IV	.	.
Ch *Cyathodes fraseri*	1.3	1.3	.	3.4	1.2	3.3	1.2	1.2	.				+	+	+	1.1	+	+		+	.	.	IV	.	.
H *Carex wakatipu*		+	+	.	+	+	+	.	.	.	.	+	+	.	1.3	2.3		2.3	2.3	3.3	1.2	+	V	.	1.2
H *Agropyron scabrum*					+	+	+	1.1	.	.	.	+	+	.	.			+	.	+	+	1.1	IV	+	+
Ch *Scleranthus uniflorus*	.	.	.	.	+	+	+	+	(+)	+	+	+	1.2	+	.		.	+	.	1.1	1.1	1.2	IV	1.1	+
H *Koeleria kurtzii*	+	.	.	.	.	+	+	+	+	(+)	.	.	.	.	.	1.1	+	+	+	+	.	.	IV	.	.
Ch *Acaena caesiiglauca*	.	+	+	1.1	+	+	+	+	.	+	2.3	1.2	+	+	+	(+)	.	.	.	+	.	.	IV	2.2	+
H *Geranium sessiliflorum*	.	.	+	+	+	+	+	+	.	.	.	.	(+)	.	.	.	+	+	.	.	.	.	IV	+	+
WIDESPREAD ADVENTIVE SPECIES																									
G *Rumex acetosella*	+	1.2			1.2	1.2	+	1.2	+	+	+	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	+	1.2	1.3	V	1.2	1.2
H *Hypochaeris radicata*	+	.	.	.	+	2.3	+	2.3	.	+	+	+	.	+	.	1.1	2.2	-	.	.	.	+	IV	+	1.2
H *Hieracium pilosella*	.	.	+	+	+	+	+	.	+	.	.	.	.	+	.					+	.	+	III		
H *Crepis capillaris*	.	.	.	.	+	.	.	+	.	.	+	+	.	+	.	1.1	.	.	.	.	+	+	III		
H *Anthoxanthum odoratum*	.	.	.	.	.	1.2	+	2.3	.	+	+	+	+	1.1	+	.	.	.	.	.	1.2	.	III	+	+
Ch *Cerastium vulgatum*	.	.	.	.	.	.	.	.	.	+	+	+	+	+	.	.	.	.	.	.	.	.	II	+	+
H *Agrostis tenuis*	+	.	.	.	+	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	II		
H *Holcus lanatus*	.	.	+	.	1.1	1.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I		
Th *Aira caryophyllea*	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	(+)	.	.	.	.	I	1.1	+
Th *Linum catharticum*	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	I		
COMPANION OR TRANSGRESSIVE SPECIES																									
Ch *Raoulia h. apice-nigra*	+																			+	+	(+)	I	.	+
H *Senecio glaucophyllus*	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	+	I	.	.
H *Vittadinia australis*	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	(+)	(+)	.	.	.	+	+	II	1.2	+
Th *Gnaphalium luteoalbum*	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	II	+	+
Ch *Acaena inermis*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	I	.	.
H *Ranunculus lappaceus*	.	.	.	.	.	+	.	.	.	+	+	.	.	+	+	.	.	+	.	.	.	+	II	.	.
H *Colobanthus strictus*	.	.	.	.	.	.	.	+	.	+	+	+	+	+	.	.	.	+	.	+	.	.	III	.	.
Th *Euphrasia zelandica*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	I	.	.
Ch *Carmichaelia monroi*	.	.	.	.	.	.	.	+	.	.	.	+	.	+	.	.	.	2.1	.	.	.	.	I	.	.
N *Carmichaelia petriei*	.	.	.	.	.	.	.	.	.	.	.	.	.	(+)	.	.	.	.	.	.	.	.	I	+	+
Ch *Muehlenbeckia axillaris*	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
G *Chrysobactron hookeri*	.	.	.	.	+	.	1.1	.	.	1.2	2.2	+	.	+	+	.	.	.	.	.	.	.	I	.	.
H *Gnaphalium collinum*	.	.	.	.	+	+	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	II	.	.
H *Poa lindsayi*	+	+	.	.	.	.	+	.	1.3	.	.	+	1.1	.	.	.	.	+	.	.	.	.	III	.	+
Ch *Cotula pectinata*	.	+	+	.	.	.	.	.	+	+	+	+	+	+	+	.	.	+	.	1.2	.	.	IV		
H *Hydrocotyle novae-zelandiae*	+	.	+	+	+	+	+	+	.	+	+	+	+	+	.	+	.	+	.	.	+	.	IV		
G *Microtis unifolia*	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	+	.	+	.	.	.	.	I	.	.
Ch *Lobelia linnaeoides*	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
H *Kirkianella novae-zelandiae*	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
H *Craspedia* indet.	.	.	+	+	.	.	+	(+)	+	.	.	.	.	(+)	.	.	.	+	.	.	.	.	I	+	.
Ch *Helichrysum bellidioides*	.	+	1.2	.	.	+	+	.	+	.	.	.	.	+	.	.	.	.	.	2.3	+	.	II	.	.
H *Blechnum penna-marina*	.	.	+	.	.	.	+	.	1.2	+	.	.	.	.	.	.	.	.	.	.	.	.	II	.	.
G *Ophioglossum coriaceum*	.	.	.	.	+	+	.	.	.	.	.	+	.	.	.	(+)	.	.	.	.	.	.	II	.	.
Ch *Helichrysum filicaule*	.	.	+	+	.	1.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
H *Agrostis subulata*	.	+	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
H *Microseris scapigera*	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
H *Gentiana corymbifera*	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
Ch *Coprosma petriei*	.	.	.	.	2.3	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
N *Discaria toumatou*	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.
H *Festuca novae-zelandiae*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	4.4	4.4

*Quat. Sed. Quaternary sedimentary rock.

facing p. 832

TABLE 2—Species of Low Frequency, Relevé Numbers Follow the Names

Dracophyllum uniflorum, 1, 3.
Lycopodium fastigiatum, 1, 3.
Pentachondra pumila, 1, 5.
Stellaria gracilenta, 2, 3.
Ourisia caespitosa, 3.
Geum parviflorum, 3.
Celmisia haastii, 3.
Poa breviglumis, 3.
Drapetes dieffenbachii, 3, 9.
Plantago spathulata, 3, 8.
Leptospermum scoparium, 5.
Coriaria angustissima, 5.
Coprosma cheesemanii, 6.
Haloragis procumbens, 6, 8.
Dichelachne crinita, 6, 8, 23.
Oxalis lactea, 8.
Oreomyrrhis ramosa, 8.
Pimelea traversii, 8.
Hymenanthera alpina, 8, 13.
Hypericum gramineum, 9, 24.
Uncinia divaricata, 11, 12.
Myosotis pygmaea, 13.
Raoulia parkii, 13.
Oxalis corniculata, 13.
Ranunculus gracilipes, 14.
Raoulia hookeri, 17.
Ranunculus sinclairii, 20.
Cotula perpusilla, 21.
Raoulia australis, 21, 24.
Wahlenbergia gracilis, 24.

Naturalised Species
Gypsophila tubulosa, 8, 22, 24.
Cirsium vulgare, 21, 22, 24.
Rosa rubiginosa, 21.
Verbascum thapsus, 22.

DEVELOPMENT OF THE COMMUNITY

In the area studied, it can be safely estimated that the present (and probably the past) timber lines are at about 4,000 ft. Relevés 1, 2, 3, 13, 16, and 17 were from above four thousand feet and could be considered as representatives of this grassland community above the timber line, modified though it may be from over a century of use. It should be emphasised, however, that above 5,000 ft *F. matthewsii* becomes less frequent and that *Poa colensoi* is more common, and *Danthonia setifolia* is abundant.

It is possible to reconstruct some of the development of this community. Above the forest line in the Ahuriri valley there is a *Danthonia rigida/Poa colensoi/Festuca matthewsii* grassland (relevés 1, 2, 3) in which there are also present quite large numbers of herbs. This grassland it seems would be quite extensive above the forest line changing, as the altitude increases, to more of a *Poa colensoi/D. rigida* grassland and leading on to herb-fields. That this grassland has, after the disappearance of beech forest, descended to lower altitudes can be interpreted from relevés 4 and 5. There are differences reflecting altitude and probably past history but these five samples are very similar floristically. Forest dimples were prominent on the site of sample plot 5. Plot 4, within the present altitudinal range for beech forest, showed more *Cyathodes fraseri* than the other relevés. The situation in the Ohau valley is much the same as in the Ahuriri, forest being present near the sites for relevés 6 and 7, while forest dimples were recorded at about 3,000 ft. At low levels in both these valleys *Festuca novae-zelandiae* is the physiognomically important grass species with *Discaria toumatou* the prominent shrub.

Comparison can now be made with the relevés from sample plots where there is at present no forest close by, although there is evidence of previous forest which probably disappeared earlier than those on the Ahuriri and Ohau sites. Plots 13, 16, and 17 were sampled at the Lindis Pass above what would have been the old forest line. Here where the rainfall is lower than in the two western valleys the same species, *D. rigida*, *F. matthewsii*,

P. colensoi, make up the bulk of the grassland, and there are no herb-field species in the list. At the lower altitudes, plots 10, 11, 12, 14, 15, 19 – after making allowance for aspect in particular – are parts of one association. In general it can be concluded that following the disappearance of forests there has been a downward migration of the community and that species with wide ecological amplitude have descended furthest. There is evidence too from relevés 23 and 24 that some species have probably come up from lower altitudes, most prominent of which is *Festuca novae-zelandiae.* Where *F. novae-zelandiae* and *F. matthewsii* meet there is a definite aspect selection between them.

Nowhere in the areas examined was *D. rigida* so dense as to exclude *Festuca matthewsii* or *Poa colensoi.* Although *P. colensoi* is a species which increases under grazing or burning, and probably *F. matthewsii* also, it is considered that in the primitive grasslands above the beech forest both species would have been present, and while it is impossible to estimate the quantities these were probably less than can be recorded today. For many other species similar difficulties occur.

There is nothing novel in this reconstruction of the development of the community, for it is evident throughout the country that there has been migration both upwards and downwards of the species which play a part in the present structure of grassland communities. It is concluded that in the case of *F. matthewsii* there has been a general downward movement along with *Danthonia rigida* and other species from the higher altitude grassland.

The most degraded communities of this grassland type still bear enough evidence of their relationships, e.g., in relevé 8 *D. rigida* is not frequent and *Poa colensoi* and *F. matthewsii* are considered present in equal amounts, but *Aciphylla aurea* is a most noticeable species and the naturalised species, *Rumex acetosella, Hypochaeris radicata* and *Anthoxanthum odoratum* are abundant. In relevés 5 and 21 *D. rigida* is absent and it is most likely that this has been brought about through burning.

In the relevés from the Benmore Range, on the driest sites sampled, *F. matthewsii* is reported on a shady face at 2,100 ft, an altitude at which *F. novae-zelandiae* is expected. At this altitude aspect differences were the same as at Lindis Pass, but a thousand feet higher *F. matthewsii* was present on both sunny and shady faces. Other low altitude occurrences of *F. matthewsii* have been recorded but no explanation can as yet be offered.

DISCUSSION

It is proposed only briefly to compare the community reported here with that reported by Barker (*loc. cit.*) the main floristic difference being the presence of *Celmisia spectabilis* at Hunters Hills and its absence from North Otago. Connor (1960a) has already drawn attention to the "Barker Line", the line of the Two Thumb Range - Hunters Hills system south of which *C. spectabilis* is not as important as it is to the north of it. *Festuca matthewsii* is not reported from Hunters Hills. These two species, both

floristically important in their respective zones, are probably sufficient to delimit major divisions of the snow-tussock grasslands, but supporting evidence is necessary and further investigation may also disclose other differences. *Anthoxanthum odoratum* was at Hunters Hills of the highest degree of presence, but in North Otago it was placed in Class III. One occurrence, plot 8, was higher in abundance/dominance than the others; *A. odoratum* was probably a contaminant in the seconds of clover seed used for oversowing.

As could be anticipated some of the species indicated by Barker as differential for her low-tussock alliance occur at moderate frequency in the snow-tussock association discussed here, e.g., *Crepis capillaris, Agropyron scabrum, Vittadinia australis,* and there are species recorded from North Otago which are absent in South Canterbury and vice-versa.

Festuca matthewsii occurs in several other districts in South Island and some of these are listed in Connor (1960a, 1960b). Any explanation for the limited distribution of *F. matthewsii* in South Island will come only from a more intensive study of the communities in which it occurs.

ACKNOWLEDGMENTS

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PESTS OF STORED PRODUCTS IN NEW ZEALAND

3—FURTHER RECORDS OF PHYCITIDAE (LEPIDOPTERA) AND PTINIDAE (COLEOPTERA)

By K. A. J. WISE, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland*

(Received for publication, 21 August 1961)

Summary

Additions and corrections to Parts 1 and 2 are given. No further species are added, but a name-change, *Ephestia kühniella* Zell. (previously *E. sericarium* (Scott)), and a synonymy, *Ptinus clavipes* Panz (= *P. hirtellus* Sturm), are noted. New records from several collections, not seen previously, are included. Information, concerning the possibility of *Ptinus tectus* Boield. being endemic in New Zealand, is collated.

INTRODUCTION

Since Parts 1 and 2 of this series (Wise 1955, 1956) were published, new information and further records of the species concerned have come to the author's attention. These, together with corrections, are noted here.

RECORDS OF SPECIES

Specimens recorded below are in the following collections: Plant Diseases Division, Auckland (P.D.D.); T. Broun Duplicate Collection, Plant Diseases Division (T.B. Dup.); A. E. Brookes collection, Plant Diseases Division (A.E.B.); C. E. Clarke collection, Auckland Museum, Auckland (C.E.C.); Entomology Division Sub-station, Lincoln (E.D.S.L.).

The two collections, T.B. Dup. and A.E.B., have been acquired by the Department of Scientific and Industrial Research since Part 2 of this series was written.

The C.E.C. collection recorded in Part 2 was presented to the Auckland Museum in 1929. In recent years the Auckland Museum and the British Museum (Natural History) jointly acquired a second collection of beetles made by the late C. E. Clarke, and a partition of specimens was made. Specimens of Ptinid beetles in the latter collection, now in the Auckland Museum, are recorded below and, as the earlier and later C.E.C. collections are being united, no distinction is made between them here.

*Present address: c/o Canterbury Museum, Christchurch, N.Z.

Family PHYCITIDAE

Ephestia kuhniella Zeller, 1879

1879. - Zeller, *Stettin.ent.Ztg.,40* : 462–473 (p. 466, *Ephestia kühniella*).

1930. – Lindsay, S. *Rec.Cant.Mus.,3* : 345–347 (p. 346, *Ephestia calidella* Gn.).

1951. – Tetley, J. H. *J.R.sanit.Inst.,N.Z.Br.,12* : 58–63 (p. 58 *Ephestia sericarium* Scott. syn. *E. kuehniella* Zell.).

1955. – Wise, K. A. J. *N.Z.J.Sci.Tech.,(B)36* : 523–530 (p. 523, *Ephestia sericarium* (Scott 1859)).

RECORDS OF OCCURRENCE. P.D.D.: – Auckland: Owairaka, P.D.D., ex *Tenebrio* culture on animal nuts, –/III/1957, 2 spec., (*K. A. J. Wise*): Whenuapai, bred ex oatmeal, –/III/1954, 1 spec., (*Medical Officer, R.N.Z.A.F.*).

Corbett and Tams (1943) synonymised *E. kühniella* with *E. sericarium* but in 1945 restored *Ephesta kühniella* as the valid name. Unfortunately, this latter paper was overlooked, and the species was recorded as *E. sericarium* in Part I.

One of Lindsay's specimens, now in the G. V. Hudson collection, was found to be of this species and was recorded in Part I of this series, but his published record was not then noted.

Tetley recorded descriptions, life history, and control measures, but much of his information was taken from literature.

Jacks (1953, b) recorded this species as being intercepted in imported foodstuffs in 1952.

Ephestia elutella (Hübner, 1796)

1938. - Anon. *12th annu.Rep.N.Z.Dep.sci.industr.Res.* 69–71 (p. 71 *Ephestia elutella*).

1939. - Anon. *13th annu.Rep.N.Z.Dep.sci.industr.Res.*, 75–80 (p. 80 *Ephestia elutella*).

RECORDS OF OCCURRENCE. A.E.B.: - Auckland, Onehunga, 6/I/1936, 1 spec., (*A. J. Hipwell*).

This species was recorded in the tobacco research reports as infesting stored tobacco.

Plodia interpunctella (Hübner, 1811–1817)

1915. – Meyrick, E. *Trans.N.Z.Inst.,47* : 201–204 (p. 202 *Plodia interpunctella* Hüb.).

1956. – Morrison, L. G. *N.Z.J.Agric.,93* : 316–324 (p. 316 *Plodia interpunctella*).

RECORDS OF OCCURRENCE. P.D.D.: – Auckland: ex peanuts in store, 8/III/1957, 3 spec., em. (ex culture) 7/1/1959, 2 spec., (*Smith*): bred ex-larvae breeding in chicory, 8/VIII/1957, 2 spec., (*Blades Fumigation*). A.E.B.: – Auckland: Onehunga, 6/I/1936, 1 spec., (*A. J. Hipwell*).

Meyrick stated "An introduced domestic species, taken by Mr Hudson in the General Post Office at Wellington; . . ." This record is presumably represented by the one specimen in the G.V.H. collection (recorded in Part I) labelled "ex office, III/1911". It is apparently the first record for New Zealand.

Morrison recorded *Ephestia* spp. and *Plodia interpunctella* in grain.

Jacks (1953, b) recorded this species as being intercepted in imported goods in 1952.

Family PTINIDAE

Mezium affine Boieldieu, 1856

RECORDS OF OCCURRENCE. P.D.D.: – Auckland: ex cotton goods, Auckland Knitting Mills, 8/II/1960, 1 spec., (*N. Broburg*).

The two locations previously recorded were within 100 yards of each other in the same street. The present location, also in Auckland City, is approximately half a mile away.

Niptus hololeucus (Faldermann, 1835)

RECORDS OF OCCURRENCE. C.E.C.: – Dunedin: 4/IV/1925, 1 spec.; 5/VI/1925, 1 spec.

These specimens appear to be the first taken in New Zealand.

Trigonogenius globulus Solier, 1849

RECORDS OF OCCURRENCE. C.E.C.: – Wellington: ex medicinal dandelion roots, 14/II/1940, 1 spec. (*Anon.*).

Ptinus tectus Boieldieu, 1856

1903. – Alfken, J. D. *Zoologische Jahrbucher, 19* : 561–628 (p. 607, *Ptinus tectus*).

1914. – Broun, T. *Bull.N.Z.Inst.,1(3)* : 143–266 (p. 195 *Ptinus fur* and *Ptinus tectus*).

1959. – Howe, R. W. *Bull.ent.Res. 50* : 287–326 (p. 294 *Ptinus fur* and *Ptinus tectus*).

RECORDS OF OCCURRENCE. P.D.D.: – Auckland: ex house, 17/II/1958, 4 spec., (*Dept. of Agriculture*). Hamilton: ex malacrate block, –/I/1959, 6 spec., (*W. R. Fletcher & Co.*). Dunedin: ex dried apricots, Speddings,

–/IV/1932, 11 spec., (*M. N. Watt*). T.B. Dup.: – Auckland: Mt. Albert, –/IV/1915, 1 spec., (in A. E. Brookes' handwriting), No data, 3 spec. (1 labelled *'Ptinus fur'* in Broun's handwriting, 1 labelled *'Ptinus fur* Europe' in Broun's handwriting, 1 unlabelled). A.E.B.: – Auckland: Mt. Albert, –/IV/1915, 1 spec., (in A. E. Brookes' handwriting and labelled 'Brookes' in Broun's handwriting): Mt Roskill, –/IV/1944, 1 spec. Methven: feeding on laurel, 30/XI/1911, 2 spec., (labelled *'Ptinus* sp.' in Brookes' handwriting and *'P. tectus* Id. by A. M. Lea'). Canterbury: 4/V/1917, 2 spec., (labelled *'Ptinus tectus'* in Brookes' handwriting). Hampden: 1 spec. Moeraki: 1 spec., (labelled 'near *Ptinus tectus'* in Brookes' handwriting). Capleston: 1 spec., (labelled *'Ptinus tectus?'* in Brookes' handwriting). Broken River: 287, 1 spec. Invercargill: 1 spec. Found amongst chicory plants, 3 spec., (*A. H. Cockayne*). (ex G. V. Hudson collection, 1 spec. labelled *'Ptinus fur* L.' in Brookes' handwriting and *'Ptinus fur'* in Broun's handwriting). *Grisellinia lucida,* 1 spec., (*'Waterhouse'* in Brookes' handwriting). 2 spec., ('coll. *G. Lewis, Ptinus* sp.' in Brookes' handwriting and *'Ptinus,* Note 2, Id. by A. M. Lea'). 24/II/1908, 2 spec., (*Lewis*). No data, 1 spec. C.E.C.: – Dunedin: Anderson Bay, Dunedin, 8/XI/1922, 1 spec.: 1923, 1 spec. E.D.S.L.: – Ashburton: ex cayenne pepper, –/X/1949, 34 spec. (*L. Lister*): ex clothes, –/XII/1947, –/XIII/1948, 3 spec., (*J. M. Hoy*). Tinwald: found in wheat, M.C.T. store, 3 spec. Timaru: ex Pinus (pupation), 19/XI/1945, 3 spec., (*D. H. Day*). In peas, 9/XII/1952, 10 spec., (*L. F. Lill*). Found in oats, 19/XII/1952, 18 spec., (*L. F. Hill*). Found in pollard, 9/VIII/1955, 7 spec., (*J. D. Storrier*).

T. Broun and A. E. Brookes were contemporaries and it is known that there was interchange of specimens between the two collections. For clarity, notes on identifications, handwriting and collecting data, are given above.

Mr G. F. Gross, Curator of Insects, South Australian Museum, Adelaide, has been unable to trace any information concerning the determinations by A. M. Lea.

Alfken (1903) recorded *Ptinus tectus* from the Chatham Islands and thus gave the first published record of this species for the New Zealand sub-region. The note "In grosser Menge" may suggest a stored products infestation. The specimens collected by the Schauinsland expedition, 1896–97, have not been seen. Mr R. W. Howe, Pest Infestation Laboratory, Slough, England, has made inquiries concerning these specimens, but has been advised by Dr Wagner, Uebersee Museum, Bremen, Germany, that the Schauinsland collection was destroyed during World War II.

Broun (1914) recorded *Ptinus fur* and *Ptinus tectus* feeding on laurel at Methven in December 1911. In Part 2 of this series a specimen of *Ptinus tectus,* (identified by Arrow) in the Broun collection, British Museum, was recorded from Methven, December 1911. Two further specimens, taken at Methven on 30 November 1911, are in the A. E. Brookes collection. Howe (1959) accepted Broun's record of *Ptinus fur* but there is no evidence that Broun ever saw a New Zealand specimen of this species. Many of his specimens are labelled *Ptinus fur* but all have proved to be *P. tectus.* It is suggested that, with the Methven specimens, Broun

noted the name he knew (viz. *fur*) then sent a specimen to England and subsequently added Arrow's identification, *Ptinus tectus*, to the record. It appears that this specimen was the basis for the record by Champion (1913). Both Champion's 1913 paper and Broun's 1914 paper were signed in December 1912.

Mr E. O. Pearson, Commonwealth Institute of Entomology, London, has advised that the only New Zealand specimens of *Ptinus tectus* in the British Museum (Natural History) general collection are as follows:

Greymouth 81. Sharp Coll. 1905. 313 (2 specimens).

Helms, New Zealand (R——er). Sharp Coll. 1905. 313 (12 specimens).

Greymouth, New Zealand (Helms). Sharp Coll. 1905. 313 (1 specimen).

Otago, New Zealand 1877 (Hutton). Sharp Coll. 1905. 313 (1 specimen).

New Zealand. Pascoe Coll. (2 specimens).

New Zealand. Pascoe Coll. 93. (1 specimen).

Howe (1959) discussed the place of origin of *Ptinus tectus* and concluded that the species originated in the Southern Hemisphere. Concerning the possibility of *P. tectus* being endemic or indigenous to New Zealand, the following historical record has been compiled.

1870, Fendale Town;*
1881(?), Greymouth;
1896–97, Chatham Islands;
1911, Methven;
1915, Mt. Albert, Auckland;
1919, Canterbury;
1874, Otago;
1893(?), New Zealand;
1908, ——;
1914, Mt. Albert, Auckland;
1917, Canterbury;
1919, Dunedin.

The remaining records are later than 1920.

There are only five apparently outdoor records of *Ptinus tectus*: *Griselinia lucida*; Methven, feeding on laurel; Seddon, Dumgree plantation, ex timber; Auckland, ex timber; found amongst chicory plants.

Thomson (1922) recorded *Ptinus fur*, citing information on outdoor records received from A. Philpott, in 1917, and W. W. Smith, in 1919. In Part 2 of this series the opinion was expressed that this information probably referred to *Ptinus tectus*. Mr E. S. Gourlay, Entomology Division, Nelson, has since advised (*pers. comm.*) that specimens in Philpott's collection, labelled *Ptinus fur* are, in fact, *Anthrenus verbasci*. In view of this misidentification and the lack of specimens collected by W. W. Smith, these records are now not accepted as valid for any Ptinid species.

Recent discussion and correspondence with many entomologists and members of expeditions to the Chatham Islands have failed to reveal any further information. In recent years no Ptinids have been collected on the Chatham Islands and none has been seen or taken outdoors in New Zealand.

*Now Fendalton, a suburb of Christchurch.

Table of Morphological Characters of Ptinid Beetles associated with Stored Products in New Zealand

	Mezium affine	*Niptus hololeucus*	*Trigonogenius globulus*	*Ptinus tectus*	*Ptinus clavipes*	*Ptinus fur*
Breadth of elevated part of head between antennal bases	Less than quarter of length of first antennal segment	More than half of length of first antennal segment	More than half of length of first antennal segment	Less than quarter of length of first antennal segment	Less than quarter of length of first antennal segment	Less than quarter of length of first antennal segment.
Vestiture of pronotum	Dense. Golden testaceous. Hairs arranged to form median longitudinal sulcus with a carina on each side	Golden. Dense, moderately short, recumbent hairs with numerous long semi-erect hairs	Dense, matted, short, recumbent, grey-brown hairs with numerous long erect dark-brown hairs	Brown with two testaceous dorso-lateral patches. Dense, moderately short, recumbent hairs with numerous longer erect hairs	Testaceous. Numerous, erect and recumbent, moderately long hairs. Hairs on disk arranged in two circles with a group arranged in a circle on each side	Testaceous. Numerous erect, and recumbent moderately long hairs. Hairs on disk arranged to form two longitudinal feebly oblique dense cushions with a group arranged to form a tuft on each side.
Scutellum	Not visible	Visible	Not visible	Visible	Visible	Visible.
Vestiture of elytra	Narrow, golden testaceous, tomentose basal collar. Some stout moderately long hairs well-spaced in basal area near collar, some very short stout hairs grouped in extreme apical region	Golden. Dense fine short recumbent hairs clothe all intervals. Longer semi-recumbent hairs arise from strial punctures. Each elytral interval bears a median row of erect hairs twice as long as those of strial punctures	Both grey-brown and dark brown short recumbent hairs densely clothe intervals. Erect dark brown hairs, some short, some long, arise from intervals only	Brown. Dense fine short recumbent hairs clothe all intervals. Longer semi-recumbent hairs arise from strial punctures. Each elytral interval bears a median row of erect hairs twice as long as those of strial punctures	Testaceous. Well-spaced, moderately long, recumbent and erect hairs arise from strial punctures and in a median row on each interval. Dorso-lateral intervals may have numerous recumbent hairs near base	Testaceous. Well-spaced, moderately long, recumbent and erect hairs arise from strial punctures and in a median row on each interval. Dorso-lateral intervals have coarse short recumbent white hairs in two transverse patches on each elytron, one on basal fourth and one on apical fourth.
Colour pattern of vestiture of elytra	Uniform	Uniform	Basal third pale with four dark patches, one near suture and one on humerus on each side. Apical two thirds more or less marbled, variable	Uniform	Uniform	Two white transverse patches on each elytron.

Jacks (1953, a) recorded *Ptinus tectus* as being intercepted in imported foodstuffs in 1951.

Ptinus fur (Linnaeus, 1758)

1914.—Broun, T. *Bull.N.Z.Inst.,1(3)* : 143–266 (p. 195 *Ptinus fur*).

1959.—Howe, R. W. *Bull.ent.Res.,50* : 287–326 (p. 294 *Ptinus fur*).

The record by Broun is discussed by Howe (1959) and in this paper under *Ptinus tectus*. It is not accepted by the present author.

In Part 2 of this series, four specimens of *P. fur* were recorded. These were collected by Helms at Greymouth and are the only known examples from New Zealand. As Greymouth is a sea-port, these specimens could well have been taken from material then recently landed and subsequently destroyed.

Ptinus clavipes Panzer, 1792

1792.—Panzer, G. W. F. *Fauna Insecta Germanica 1* : Pls. 24. (*Ptinus clavipes*).

1956.—Wise, K. A. J. *N.Z.J.Sci.Tech.(B)37* : 503–508 (p. 506, *Ptinus hirtellus* Sturm, 1837).

RECORDS OF OCCURRENCE. P.D.D.: Auckland: ex clothing warehouse, 29/VII/1954, 1 spec., (*Ross & Glendining Ltd.*): Henderson, Ranui, ex open tin with insect remains, poultry feed shed, 14/VII/1956, 1 spec., (*K. A. J. Wise*).

Moore (1957) synonymised *Ptinus hirtellus* Sturm, 1837 with *P. clavipes*.

TABLE OF MORPHOLOGICAL CHARACTERS OF PTINID BEETLES

The table is given to provide additional information for the determination of Ptinid beetles associated with stored products in New Zealand. *Ptinus fur* is included for comparative purposes although it is not established in this country.

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Director, Commonwealth Institute of Entomology, London, England; Mr R. D. Pope, Commonwealth Institute of Entomology, London, England; Mr E. G. Turbott, Assistant Director, Canterbury Museum, Christchurch; Mr C. J. Watt, Auckland; and Dr M. N. Watt, Dunedin.

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JACKS, H. 1953, a: Plant Quarantine, I. List of Plant Diseases and Pests Intercepted in New Zealand in 1951. *N.Z. J. Sci. Tech. (A) 35:* 169–71.

————1953, b: Plant Quarantine, II. List of Plant Diseases and Pests Intercepted in New Zealand in 1952. *N.Z. J. Sci. Tech. (A) 35:* 273–5.

MOORE, B. P. 1957: The Identity of *Ptinus latro* auct. (Coleoptera: Ptinidae). *Proc. R. ent. Soc., Lond. (B) 26*: 199–202.

THOMSON, G. M. 1922: "The Naturalization of Animals and Plants in New Zealand." C.U.P. 607 pp.

WISE, K. A. J. 1955: Pests of Stored Products in New Zealand, I. Family Phycitidae (Lepidoptera). *N.Z. J. Sci. Tech. (B) 36:* 523–30.

————1956: Pests of Stored Products in New Zealand, II. Family Ptinidae (Coleoptera). *N.Z. J. Sci. Tech. (B) 37:* 503–8.

THE CHEMICAL COMPOSITION OF RAINWATER AT TAITA, NEW ZEALAND, 1956–1958

By R. B. MILLER Soil Bureau, Department of Scientific and Industrial Research.

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Summary

Rainwater has been collected monthly for three years at the Taita Experimental Station, 5 miles from the coast near Wellington, and analysed for the main elements present. The salt found, excluding bicarbonate, averaged 190 lb/ac/yr (212 kg/ha/yr) of which nearly 80% was sodium and chloride. Sulphate, 22 lb/ac/yr, and magnesium, 10 lb/ac/yr, were next in amount, followed by potassium and calcium with 6 lb/ac/yr each. Phosphate was very low (less than 1 lb/ac/yr). Total nitrogen was measured for a period and found to be double the inorganic plus albuminoid nitrogen. Accessions to the soil of nitrogen are probably not less than 3 lb/ac/yr.

The ionic ratios showed that in periods with southerly storms the salt tended to approach the composition of sea water, and at other times calcium and potassium, and to a lesser degree magnesium and sulphate, reached higher proportions.

INTRODUCTION

The earliest New Zealand rainwater analyses were made by Gray (1888, 1910) at Lincoln (Fig. 1). The first paper reports on samples taken monthly from January 1884 to June 1888. The following results were obtained:

	lb/ac/yr*
Dissolved solids	179
Albuminoid-N	0·5
Ammonia-N	0·5
Nitrate-N	1
Sulphur	5
Chloride	61

The second paper gives results of samples collected from July 1907, to June 1909. The results were similar except that, because of lower winds, chloride averaged only 35 lb/ac/yr. For the year 1908–9 four more elements were determined, with the following results:

	lb/ac/yr
Sodium	44
Magnesium	2·6
Potassium	4·7
Calcium	7·0

*lb/ac × 1·12 = kg/ha.

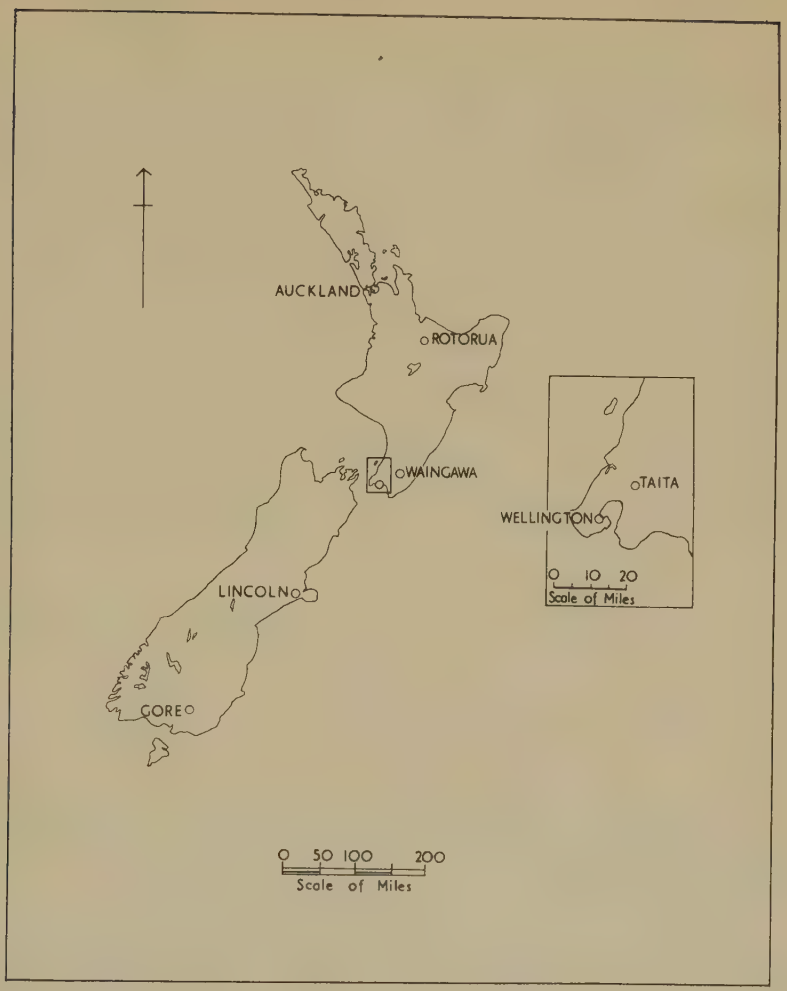

FIG. 1—Locality map showing collecting sites referred to in the text.

Blakemore (1953) determined chloride in monthly rainwater samples from nine stations in the southern part of the North Island in the period September 1947 to January 1951. At least 12 samples were obtained from each station. The quantity of chloride deposited fell off rapidly from 210 lb/ac/yr on the coast at Wellington to 48 lb/ac/yr 6 miles inland, and then more slowly to 36 lb/ac/yr at Waingawa, 38 miles inland.

Will (1959) in an experiment on nutrient return in forests measured calcium, potassium, sodium, and phosphorus in rainwater at three sites near Rotorua between December 1954, and November 1957. Mean values obtained were:

	lb/ac/yr
Sodium	29
Potassium	5·2
Calcium	2·9
Phosphorus	0·3

Gray's interest in the form of nitrogen in rain was taken up again by Wilson (1959, a, b) who analysed snow samples from high altitudes and found that most of the nitrogen was not in nitrate, which was not found, nor in ammonia, but was in the organic (albuminoid) fraction estimated by distillation with alkaline permanganate. He calculated that New Zealand soils received several pounds per acre per year of nitrogen in organic form and showed that it probably came from the sea surface.

T. W. Collie of the New Zealand Soil Bureau (pers. comm.) measured total nitrogen by sulphuric acid digestion in three-monthly rainwater samples from Gore taken in two periods, 1955–6 and 1957–8, and found an average of 6 lb/ac/yr. Further results from the Gore samples gave values of between 5 and 10 lb/ac/yr for magnesium, potassium, calcium, and sulphur. There were nearly 30 and 60 lb/ac/yr of sodium and chloride respectively. Phosphorus was very low.

In the past few years, particularly since it has been established that sulphur is an important limiting nutrient in pasture growth in many parts of New Zealand, some systematic sulphur measurements have been started. B. W. Doak (pers. comm.) has found at Otara Research Station just south of Auckland that some 12 lb/ac/yr of sulphur is carried down by the rainwater. This is high because of the proximity of industrial plants and of wide areas of tidal mud flats, H_2S from which causes serious local atmospheric pollution problems. E. B. Davies, Rukuhia Soil Research Station (pers. comm.) has had rainwater collected at a number of rural sites from various parts of New Zealand and found values for sulphur of between 0·4 and 2·8 lb/ac/yr.

These results are insufficient for general conclusions to be drawn about the distribution of the various elements in New Zealand precipitation but they do show that the levels are similar to those in other countries where atmospheric chemical conditions are strongly influenced by the sea (Egnér and Eriksson, 1955). Except possibly for Gray's work on nitrogen and sulphur, none of the investigations was carried on long enough to get reliable mean values, and only Blakemore covered enough sites to show how the amount of salt in the rainwater changes with distance from the coast.

The present work was done as part of a study of the nutrient cycle in forest. Rainwater has been collected and analysed monthly for three years at the Taita Experimental Station of the New Zealand Soil Bureau. The results are of interest because comparatively little systematic work on atmospheric chemistry has been done in the South Pacific Area (Eriksson, 1952).

EXPERIMENTAL METHODS

The rainwater was sampled at the Taita Experimental Station of the Soil Bureau at the bottom of the 34 acre, north-facing, central catchment which is used for the study of soils under regenerating native forest. The samples were collected in a polythene bottle using a glass filter funnel; the bottle was changed monthly. The daily amount of rain was found from a standard 5-in. rain-gauge alongside (R. Q. Packard, pers. comm.).

In the laboratory the water was filtered, pH and specific conductivity determined, and chloride and bicarbonate found by titration of 50 ml aliquots with 0·02N $Hg(NO_3)_2$ and 0·02N HCl respectively. Then a litre of water was taken to dryness, ignited at 450° to 500°C for 30 min and the residue digested 1 hr with 10 me. HCl. After filtering, the solution was made up to 50 ml. On this solution sodium and potassium were measured on the flame photometer, calcium and magnesium by titration with EDTA (Knight, 1951; Brunisholz *et al.*, 1953), phosphate by the molybdenum blue method using $SnCl_2$ as reducing agent; and sulphate by titration of excess $BaCl_2$ after precipitation of $BaSO_4$ (Sijderius, 1954). The methods used were those described by Metson (1956) unless otherwise stated. The results are expressed as mg/m^2 of the various elements.

A check was made on the possibility raised by Murphy and Riley (1956) of adsorption of phosphate by polythene. It was found that under the conditions of this experiment adsorption did not appear to cause any appreciable error.

RESULTS AND DISCUSSION

Total Salts

The analysis results are given in Table 1. The annual totals (Table 2) were considerable, ranging up to 214 lb/ac/yr of salt and averaging 190 lb/ac/yr (212 kg/ha/yr). Bicarbonate was not included in these totals because the amount in the sample when analysed undoubtedly differed from that in the rain when it fell. The average of 190 lb/ac/yr was obtained from only three years' results but as the rainfall over the period was more or less normal the result is probably not far from the true mean value. There was an unusually windy period in late 1957 and early 1958 but this did not appear to affect the totals.

Of the total salt, sodium and chloride made up 78%, sulphate 11%, and potassium, magnesium, and calcium between 3% and 5%. Phosphorus was very low. Of the elements of major agricultural importance as plant nutrients, only the 22 lb/ac/yr of sulphate and the 10 lb/ac/yr of magnesium would be likely to be significant. Eriksson (1959a) has estimated that the total accessions of oceanic salts over Scandinavia are about three times the accessions in precipitation. In New Zealand, because of the higher and more frequent rainfall, the proportion of salt deposited directly on the plants and soil is probably lower than in Scandinavia. However, it is possible that with this source added to the rainfall the accessions of potassium are also significant.

TABLE 1—The Chemical Composition of Rainwater, Taita 1956–1959

Sampling Date	Days in Period	Rainfall mm	S	mg/m² Cl	N	P	Na	K	Mg	Ca	pH	μ val./l HCO_3^-	Ohm^{-1} cm^{-1} K.10^6
20.2.56	34	112											
20.3.56	29	137	101	874		1·4	725	107	100	82			
18.4.56	29	79	32	476		1·6	309	62	77	143			38
21.5.56	29	166	173	1472		1·2	840	65	101	133	5·8	230	37
20.6.56	34	187	120	1326		1·0	602	73	136	38	5·6	200	25
17.7.56	27	316	364	5155		3·3	2544	124	423	127	5·7	130	66
17.8.56	31	152	158	539		0·9	315	59	55	61	5·4	170	18
17.9.56	31	30	48	330		0·6	207	24	37	30	6·7	190	51
17.10.56	30	59	47	251		1·6	136	23	36	47	6·1	190	25
16.11.56	30	98	56	521		2·4	271	38	107	98	5·8	190	29
18.12.56	31	55	29	351		1·9	278	129	33	66	6·2	220	27
17.1.57	31	63	39	402		1·4	217	25	38	25	5·8	160	32
18.2.57	32	37	15	157		1·2	170	20	23	15	6·2	180	22
19.3.57	29	108	78	460		3·5	497	34	39	43	5·8	160	20
23.4.57	35	82	59	436		1·0	188	32	50	16	5·1	140	27
21.5.57	28	298	95	4222		6·4	1580	105	362	119	5·6	170	55
19.6.57	29	113	36	922		1·9	312	31	110	45	5·4	150	33
17.7.57	28	123	65	960		0·6	425	39	135	49	5·4	160	34
15.8.57	29	49	14	625		0·8	270	27	83	20	5·6	160	57
17.9.57	33	139	29	987		1·3	480	60	101	28	5·8	180	35
17.10.57	30	155	55	1045		0·8	499	36	113	62	5·4	180	32
18.11.57	32	82	13	2180		0·5	1040	80	159	61	5·7	160	110
18.12.57	30	208	77	368		2·1	574	211	152	167	5·9	200	25
17.1.58	30	105	40	1042		1·3	386	41	51	42	5·4	180	28

26.2.58	40	165	185	1760		4·8	759	90	158	132	6·0	180	53
19.3.58	21	83	35	528		3·1	229	23	40	50	5·7	200	27
18.4.58	30	41	57	696	18	0·4	340	35	49	33	5·6	200	76
21.5.58	33	182	154	2580	42	1·6	1130	100	175	109	4·6	190	59
18.6.58	28	55	69	878	15	0·9	470	37	66	44	4·7	190	74
18.7.58	30	112	13	79	17	2·5	129	26	27	22	5·6	200	11
19.8.58	32	118	32	504	12	1·8	272	32	42	47	5·1	190	24
19.9.58	31	50	14	248	20	2·7	138	10	24	20	5·5	210	28
19.10.58	27	69	23	659	13	1·7	382	22	58	28	6·7	200	46
19.11.58	34	69	29	344	19	0·8	143	40	33	28	5·0	240	23
19.12.58	30	82	27	174	37	1·6	113	29	30	33	4·5	200	14
16.1.59	28	76	23	216	37	2·6	105	27	18	30	4·6	200	13
25.5.59–24.6.59	30	74	50	788	39	1·5	374	51	57	47	4·7	160	48
18.8.59–21.9.59	34	174	45	557	63	2·3	301	51	67	97	4·9	170	19
30.10.59	39	129	29	1020	66	1·4	416	61	62	72	5·5	190	31
17.12.59	48	152		1240	106	2·7	663	137	73	182	4·6	220	43
18.1.60	32	17		350	24	2·1	149	30	14	31	4·8	260	84

TABLE 2—Annual Quantities of Various Elements in Rainwater

Year	Rainfall in.	S	Cl	N	P	Na	K	Mg	Ca	Sum
					lb/ac/yr					
1956	57	11·3	114		0·17	62	7·1	11·2	8·3	214
1957	59	5·2	120		0·19	58	6·4	12·3	6·0	208
1958	43	5·9	78	2·5*	0·22	38	4·2	6·4	5·2	140
Mean	53	7·5	104	2·5	0·20	53	5·9	10·0	6·5	190
	mm				kg/ha/yr					
Mean	1352	8·4	116	2·8	0·22	59	6·6	11·2	7·3	212

*Calculated as for 12 months.

Total Nitrogen

In the 1958 and 1959 results it should be noted that the nitrogen figures are totals, obtained by Kjeldahl digestions. T. W. Collie (pers. comm.) found that these totals were very much higher than inorganic (nitrate plus ammonia) nitrogen, thus showing that there was an important fraction of organic nitrogen present. Wilson (1959a) later found that there was more albuminoid nitrogen than inorganic nitrogen in a number of snow samples. Accordingly a series of samples was analysed for all three fractions, inorganic, albuminoid, and total nitrogen. From 12 monthly samples taken in 1958 and 1959 the following average results were obtained (mg/m²/month):

ammonia-N	7
albuminoid-N	12
non-albuminoid organic-N	18
	37

The quantities of nitrate-nitrogen were very small. The proportions agreed with those found by Collie and by Wilson and show that the albuminoid fraction was about double and the total about five times the inorganic fraction. It therefore appeared that there were three main nitrogen fractions of which the non-albuminoid organic fraction was the largest. This fraction does not appear to have been previously studied in rainwater and obviously deserves more attention. The available evidence (Wilson, 1959b, Eriksson, 1959b) indicates that some at least of the organic nitrogen comes from the sea.

Ionic Ratios

In the annual rainwater totals the proportions of sodium and chloride were fairly close to those found in sea water. In relation to these the proportions of sulphur and magnesium were about 50% higher, and those of potassium and calcium about 300% higher than in the sea. The monthly figures more or less retained these proportions although it was noticeable that the variations from month to month of sodium and of chloride were

much greater than those of the other elements. Sodium and chloride gave very high peak levels from time to time, particularly in autumn and spring. In these peak months the proportions of magnesium, sulphur, potassium, and calcium came much closer to those in sea water.

Table 3 contains some ionic ratios on a chloride basis for the 14 months with chloride accessions of less than 500 mg/m², and for 4 peak months with chloride accessions of more than 2,000 mg/m². The 3 year average ratios and the ratios in sea water are also included. These and the rest of the results showed that as the quantity of salt increased the proportions tended to approach that of sea water.

TABLE 3—Ionic Ratios in Rainwater 1956–1958

Mass Ratio	14 Low Months	3 Year Average	4 Peak Months	Sea Water
Cl/Na	1·3	2·0	2·2	1·8
Cl/K	6	18	35	50
Cl/Ca	6	16	34	47
Cl/Mg	7	10	13	15
Cl/S	8	14	22	22

This suggested that in peak periods much of the salt comes in as spray direct from the sea. Meteorological records showed that in fact there had been severe southerly storms in these peak months. Winds in these "southerly busters" often exceed 60 m.p.h. (30 m/sec) with gusts reaching 100 m.p.h., and sea spray penetrates miles inland. There is no doubt that the peaks are due to these storms.

The prevailing northerly wind is also often strong but it has to come more than nine miles from the coast over hills rising to about 1,200 ft. The salt in the atmosphere under these conditions, as shown by the average rainwater composition, contained relatively more sulphate, magnesium, potassium, and calcium than does sea water. The excess was probably derived partly from the sea surface (Wilson 1959b) and partly from sources on land – dust, smoke, fertilisers, etc. While the annual totals of salt were closely proportional to the total rainfall the monthly figures were not necessarily so, and the amounts of salt collected were related also to wind.

When the ionic ratios are considered on a chemical equivalent basis a mean figure of 0·27 me./l is obtained for the sum of chloride sulphate and phosphate and 0·33 me./l for the sum of calcium, magnesium, potassium, and sodium. The difference is more than made up by the bicarbonate.

Comparison with Other Results

The results in Table 1 were of the order expected from results from other parts of New Zealand. Gray's Lincoln site was 15 miles from the coast and his results were lower than those from Taita. Will's figures from

Rotorua which is 30 miles from the nearest coast and Collie's figures from Gore, 35 miles from the coast, were still lower. Two of Blakemore's sites, 4 miles inland gave similar chloride figures.

CONCLUSIONS

An average of 190 lb/ac/yr of salt has been found in rainwater at the Taita Experimental Station, and although samples were collected for only three years it is considered that this figure is probably fairly close to the mean value. The results were similar to those expected from the small amount of work previously done in New Zealand, and from overseas results.

Sodium and chloride were the dominant ions, making up nearly 80% of the salts measured, but the amounts of sulphate and magnesium could be significant for plant nutrition in the area. If the additional salt deposited on the soil directly from the air is considered, the amount of potassium might also be important. Phosphorus is very low.

Total nitrogen was measured on some of the samples and found to be about double the inorganic plus albuminoid nitrogen. The non-albuminoid organic fraction is an important one that deserves further study. The total contribution from rainwater to the nitrogen cycle at Taita would probably be not less than 3 lb/ac/yr.

A comparison of the ionic ratios of the rainwater with that of sea water indicated that most of the salt (i.e., that which came in during southerly storms in which very high winds are accompanied by rain) was similar to sea salt and was derived largely from spray. The salt in the atmosphere at other times comes a greater distance overland in the prevailing winds from the north. It has a higher proportion of magnesium and sulphate and a much higher proportion of potassium and calcium than sea water and probably contains a higher component of surface water (Wilson 1959b), and considerable terrestrial dust.

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